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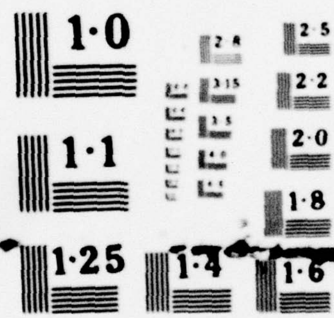

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Report DAAK01-76-C-1100

SEMI-ADDITIVE PROCESSES FOR FABRICATION OF PRINTED WIRING BOARDS

AD A075975

Jack Quintana
Hughes Aircraft Company
Fullerton, CA 92634

JUNE 1979

Final Report for Period 1 July 1976 – 31 December 1978
FR 79-12-190

Prepared for

U.S. ARMY MISSILE RESEARCH AND DEVELOPMENT COMMAND
Redstone Arsenal, AL 35809

ADVANCED SYSTEMS DEVELOPMENT AND MANUFACTURING TECHNOLOGY DIRECTORATE, DRDMI-EAA
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Printed wiring boards fabricated by semi-additive processes from four laminate types have met the requirements of MIL-P-13949, MIL-P-5110, and selected tests of MIL-P-55640. Laminate types consisted of ultra-thin copper with peelable carrier, ultra-thin copper with etchable carrier, sacrificial foil, and adhesively-coated nonclad.

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Material screening utilized peel strength testing and visual examination for qualification.

Investigations of laminate surface condition, "seeded" versus "nonseeded" resin, electroless copper catalyst size, and variations in processing parameters were carried out. The processes developed incorporate normal subtractive PWB fabrication techniques to a large extent. The methodology is adaptable to the production of all-copper circuitry with solder coating by use of solder dip/air leveling equipment.

This technique lends itself to permanent solder mask use. Results indicate intrinsic benefits related to design, reliability, and environmental pollution control.

A cost/value analysis indicates that PWBs fabricated from ultra-thin copper with peelable carrier results in an estimated 9-percent reduction in labor costs. A similar cost savings is realized in PWBs produced by semi-additive techniques.

Verification of the processes for PWB fabrication using ultra-thin copper-clad material was accomplished in a pilot production line environment. PWBs fabricated in this line were positively tested and qualified to the requirements of MIL-P-55110.

A design package of an automated production line was assembled and delivered to MIRADCOM. A 16-mm motion picture of 15 minute duration (color and sound) was prepared and delivered to MIRADCOM. At the conclusion of the program, a 2-day debriefing session was held at Hughes-Fullerton. The data and results obtained in this program were passed on to the attendees and included all the information in this final report.

PREFACE

This final report documents the results obtained during the MM&T Program entitled "Semi-Additive Processes for Fabrication of Printed Wiring Boards." This report was prepared by the Hughes Aircraft Company, Fullerton, California, under contract DAAK01-76-C-1100.

The effort was sponsored by U.S. Army Missile Research and Development Command (MIRADCOM).

The principal Hughes contributors were Jack Quintana, Project Manager, T. Weismuller, B. Havens, J. Semar and J. Hamilton. The work covered by this report was performed between 1 July 1976 and 31 December 1978.

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SUMMARY

Four Epoxy-Glass Laminate Types Were Evaluated for Conformance to Military Specifications

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SUMMARY OF PHASE I TASKS

- Development of Background Information
  - Literature search
  - Military/industry survey
- Materials Assessment and Selection of Candidate Laminates
  - Material procurement
  - Test pattern generation and fabrication
  - Material selection and testing
- Process Evaluation and Optimization
  - Surface preparation definition
  - Electroless copper evaluation
  - Peel strength tests
  - Documentation of processes
  - Qualification of processes
- Projected Cost/Value Analysis
  - Material and labor costs
  - Comparison with subtractive process

Phase I was divided into four major work tasks. Primary effort within the first task was a literature search for published articles and reports on semi-additive and ultra-thin copper laminate printed wiring board methodology. The purpose of this task was to assure coverage of processes, materials, and other ancillary information relating to the program to eliminate duplication of effort.

The next task was devoted to the assessment and selection of candidate materials. A literature review and survey of laminators indicated that the materials fall into two categories: ultra-thin copper-clad and unclad semi-additive type laminates. Test panels were fabricated from each of the candidate materials and subjected to pre-screening tests including visual, warp and twist, peel strength, and plating adhesion. From the results of these tests, four material types were chosen for the next task. In this task, process sequences were prepared for fabricating test panels using the four candidate material types. A Hughes-modified IPC test pattern was used to produce the image on the test panels to provide coupons for qualification testing of the various material types. Peel strength tests were used as an important criteria in the qualification of an optimum process. The surfaces of the unclad laminates were examined using a scanning electron microscope after various surface preparations to correlate the surface finish with peel strength. Finally, the optimized processes were documented for each of the four material types, and each process was then qualified by testing four panels of each type to the requirements of MIL-P-55110.

In the last task, data was obtained relative to the cost of fabricating PWBs using the best of the developed materials and processes. In addition, a preliminary cost analysis of the fabrication process was performed for one of the ultra-thin copper-clad and one of the unclad laminates.

Pilot Production Line Was Established and Qualified for Production of Ultra-Thin Copper-Clad PWBs

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HUGHES AIRCRAFT COMPANY
GROUND SYSTEMS GROUP
FULLERTON, CALIFORNIA

99068-202

SUMMARY OF PHASE II TASKS

- Optimization and Verification of Selected Process
  - Fabricate PWBs
  - Assure routine producibility
  - Test PWBs to military specifications
- Design, Establishment and Qualification of Pilot Production Line
  - Routinely produce PWBs
  - Qualify PWBs to MIL-P-55110
  - Produce motion picture of process
- Design of Automated Production Facility
  - Equipment specifications and layout
  - Flow chart for PWB fabrication
- Two-Day Industry/Government Debriefing Session
- Final Report

A major task in Phase II of this program was devoted to the optimization and verification of the processes for PWB fabrication using ultra-thin copper-clad material. This was accomplished in a pilot production facility established and qualified for this purpose. PWBs were produced in this line and routinely tested to the requirements of MIL-P-55110. Five sets of PWBs fabricated in this pilot line were delivered to MIRADCOM for their evaluation along with a 15-minute 16-mm color/sound motion picture of the pilot line operation. An additional task in Phase II was the design and documentation of an automated production line for the production of PWBs using this technology. This included a process flow chart, equipment specifications and layout, which were packaged into handbook form for delivery to MIRADCOM.

At the conclusion of the program, a two-day industry/government debriefing session was held at Hughes-Fullerton. The data and results obtained in this program were passed on to the attendees.

PWBs Produced From Semi-Additive and Ultra-Thin Copper-Clad Laminates Meet Requirements of MIL-P-55110

HUGHES
HUGHES AIRCRAFT COMPANY
GROUND SYSTEMS GROUP
FULLERTON CALIFORNIA

99068-203

RESULTS AND CONCLUSIONS

- PWBs fabricated in pilot production line from the four materials qualify to MIL-P-55110
- Adhesive-coated PWBs must be treated in FC/TMC to pass IR tests after exposure to humidity
- No "resin bleed through" or drill burr problems
- 50 Å catalyst/high-rate electroless copper system provides good peel strength
- Production of "all-copper" type PWBs resulted in labor savings of 7 to 9%
  - "All-copper" circuits were successfully solder-coated using SCL
  - PWBs with solder mask were solder-coated successfully using SCL
- Laminate material costs relative to standard 1 oz/ft^2
  - Higher for ultra-thin copper and adhesive-coated
  - Lower for sacrificial foil
- Ultra-thin copper-clad processes can be implemented into subtractive lines

PWBs fabricated using ultra-thin copper-clad, adhesive-coated, and sacrificial foil laminate materials qualified to MIL-P-55110. A pilot production line was established for the routine fabrication and qualification of PWBs using the ultra-thin copper-clad material. There was no "resin bleed through" or drill bur problems on either type of ultra-thin copper-clad laminate material (peelable or etchable carrier). The ultra-thin copper-clad process can be implemented into a standard subtractive line with minimal conversion costs.

A high-rate electroless copper system employing a 50Å catalyst solution was successfully used to produce PWBs in a pilot production environment. A minimum thickness of 70 microinches of electroless copper was sufficient to eliminate the need for panel plating. This system also provided good peel strength qualities of the deposited copper on both types of unclad laminates (the adhesive-coated and the sacrificial foil).

Using the modified processes described herein, "all-copper" PWBs were produced by both the ultra-thin copper-clad and semi-additive processes. These PWBs were successfully solder-coated using solder coater/air leveling equipment (SCL) thus eliminating conventional tin/lead plating and fusing operations. High-density circuits were also produced using the modified processes. They were coated with a permanent solder mask, and then the terminal areas and PTHs were solder coated using the SCL process. The use of these processes on the all-copper PWBs resulted in a projected labor cost savings of 7 to 9 percent. Material costs were based on modest quantity lot sizes, and compared with standard MIL-P-13949/4 laminates. The ultra-thin copper-clad materials were 14 to 16 percent higher than the standard 1 oz/ft^2 material while the cost of adhesive-coated laminates was 9 percent higher. In contrast, the sacrificial foil laminates were priced 7 percent lower than the standard.

SECTION 1
BACKGROUND AND OBJECTIVES

1. THE NEED FOR NEW PWB PRODUCTION TECHNIQUES

The methodologies presently being used for PWB fabrication need improvements or changes in order to satisfy the requirements for higher density circuitry. The development of ultra-thin copper-clad, and semi-additive technologies meet this requirement.

Printed wiring board (PWB) technology, in use for the fabrication of military electronic equipment for more than a quarter of a century, is based on the subtractive process wherein a resist image of the circuits is applied to a metal-clad dielectric laminate and the excess metal etched away. A modification and improvement of this process utilizing pattern plating techniques evolved with the development of reliable photoresist systems resistant to the effects of plating chemicals. This allowed the PWB fabricator to electroplate the copper and tin-lead deposits only in the PTHs and circuitry patterns. Once plated, the resist is removed and the unwanted copper foil is etched away. The tin-lead plating acts as an etch resist thereby preventing the copper in the PTHs and circuitry patterns from being etched away. By using this pattern plate and etch technique with thin copper foil laminates*, the reduction in circuit line widths is much less than those produced using the standard subtractive process. This is due to the fact that only the foil thickness must be etched away when using the pattern plate process whereas the foil plus the copper plating thickness must be removed when using the subtractive process. Therefore, current processes have been refined so that reliable, high-density PWBs can be produced in quantity with 0.010-inch lines and spaces.

However, recent trends requiring lightweight, compact electronic systems has led to increased miniaturization. To achieve the required high-density electrical packaging, PWB designs must incorporate conductor widths and spacings less than the presently allowed 0.010-inch minimum. Therefore a need exists to develop the materials and processes capable of producing PWBs with 0.005-inch lines and spaces. Materials such as the 5-micron ultra-thin copper-clad laminates, adhesive-coated and sacrificial foil unclad laminates are candidates for this evaluation.

This MM&T program was conducted in order to answer the following needs:

- Other methodologies for production of high-density PWBs (0.005-inch lines/spaces)
- Materials meeting MIL-SPEC requirements
- Processes capable of producing PWBs acceptable to the military
- Processes easily implementable into standard subtractive production lines.

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*0.5 oz/ft^2 is the minimum thickness of copper foil allowed by military specifications at this writing.

2. OBJECTIVE OF THE MANUFACTURING METHODS AND TECHNOLOGY PROGRAM

The program was devoted to the assessment, selection and qualification of materials and processes suitable for fabricating printed wiring boards (PWBs) using semi-additive and ultra-thin, copper-clad technologies. The resultant PWBs fabricated with these materials and processes must qualify to the requirements of MIL-P-55110.

Hughes Aircraft Company, Ground Systems Group, Fullerton, California, was awarded a contract for a Manufacturing Methods and Technology Program on Semi-Additive Processes for the Fabrication of Printed Wiring Boards. The contract began 1 July 1976 and consisted of two major phases as summarized in Table 1.

Phase I (18 months) was a developmental effort devoted to the assessment, selection, and qualification of materials and processes suitable for fabricating printed wiring boards using the semi-additive and ultra-thin copper-clad processes. The PWBs produced by these prototype processes were to result in a militarily acceptable end-product (meeting requirements of MIL-STD-275 and MIL-P-55110). The boards were to have high reliability, good producibility, and were to be lower in cost than the subtractive process. The technology also was to be readily adapted to current PWB production systems with minimal conversion costs.

In Phase II (12 months), the objective was to establish a pilot production line using the optimized process developed in Phase I. The pilot production line was to be used to fabricate quantities of PWBs in order to qualify the process and the line. In addition, an automated facility for PWB fabrication was to be designed and delivered to MIRADCOM. Finally, a government/industry debriefing session was to be held wherein the results of this program would be disseminated to government and industry representatives at a two-day session. A 15-minute 16-mm color and sound movie was to be made depicting the processes used for the developed PWB processes.

TABLE 1. SEMI-ADDITIVE PROGRAM OBJECTIVES

Phase I

- Material assessment and selection
- Process evaluation and development
- Cost/value analysis

Phase II

- Process optimization
- Design, establish and qualify a pilot production line
- Fabrication of PWBs and qualification to MIL-Specs
- Automated production line design
- 16mm-motion picture in color and sound depicting processes
- Two-day industry/government demonstration

SECTION 2
PHASE I – DEVELOPMENT EFFORT

1. OVERVIEW OF PHASE I EFFORT

At the conclusion of the Phase I effort, four material types of PWB laminates were found suitable for military specifications: two types of ultra-thin copper-clad laminates (peelable and etchable carrier); and two types of unclad laminates (adhesive coated and sacrificial foil).

Phase I was divided into five tasks: coordination meetings; development of background information; materials assessment and selection; process evaluation and development of optimized process; projected cost/value analysis; and documentation. Figure 1 illustrates the relation between tasks.

Five coordination meetings between Hughes and MIRADCOM were held during the Phase I portion of the program. The purpose of these meetings was two-fold: to assure that all technical milestones of the program are understood by both parties and to establish an immediate person-to-person technical relationship between Hughes and MIRADCOM personnel to ensure maximum communication during the program.

Primary effort within Task 2 was a literature search for published articles and reports on semi-additive and ultra-thin copper laminate printed wiring board methodology. The purpose of this task was to assure coverage of processes, materials, and other ancillary information that would relate to the program and eliminate duplication of effort. Sources utilized in acquiring the bibliographic material included the Defense Documentation Center-Report Bibliography, National Technical Information Service, Engineering Index, National Aeronautics and Space Administration, Institute of Printed Circuits, California Circuits Association, Aerospace Industries Association, Electronic Industries Association. As a result, 107 bibliographic references (spanning the years from 1968 to present) were acquired and reviewed. These are listed in Appendix A-1.

Task 3 was devoted to the assessment and selection of candidate materials for use in this program. A review of the literature and a survey of laminators revealed that the materials fell into two categories: the ultra-thin copper-clad and the unclad semi-additive type laminates. Test panels were fabricated from each of the candidate material types chosen and subjected to pre-screening tests including visual, warp and twist, peel strength, and plating adhesion. From the results of the pre-screening tests, four material types were chosen for Task 4 – process evaluation and optimization.

In Task 4, process sequences were prepared for fabricating test panels using the four candidate material types. A Hughes-modified IPC test pattern was used to produce the image on the test panels. This provided sufficient coupons for the qualification testing of the various material types. Peel strength tests were used as an important criteria in the qualification of an optimum process. The surfaces of the unclad laminates were examined using the scanning electron microscope (SEM) after various surface preparations to correlate the surface finish with peel strength. Finally, the optimized processes were documented for each of the four material types, and each process was then qualified by testing four panels of each type to the requirements of MIL-P-55110.

In Task 5, data was obtained relative to the cost of fabricating PWBs using the best of the developed materials and processes. The basic cost of the laminate materials based on quantities up to 200,000 square feet was obtained from five vendors. In addition, a preliminary cost analysis of the fabrication process was performed employing one of the ultra-thin copper-clad and one of the unclad laminates.

The documentation task consisted of 17 monthly letter reports to MIRADCOM detailing technical achievements, problems encountered, methods investigated in solving the problems, and a labor/financial status.

In addition, an interim report was prepared at the conclusion of the Phase I effort for the period of 1 July 1976 to 31 December 1977 (Report DAAK40-76-C-1100).

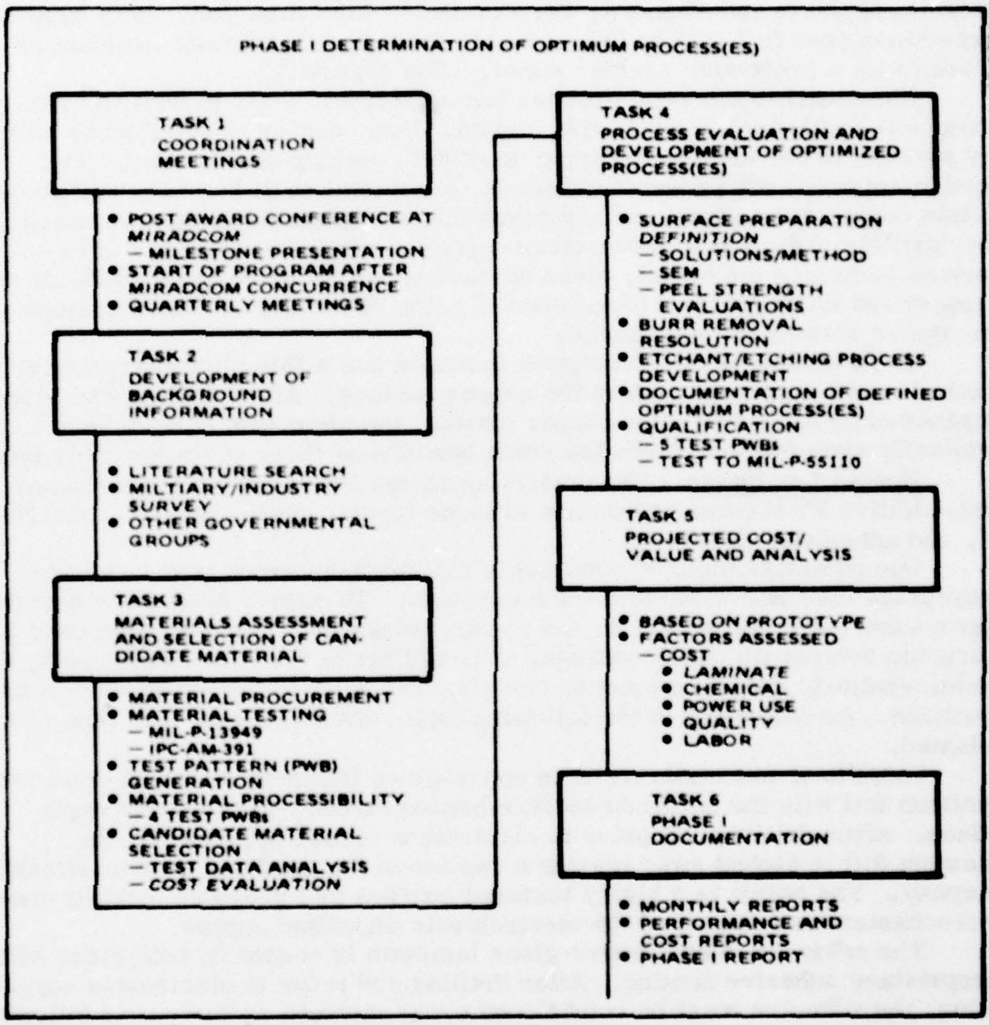


Figure 1. Flow of Major Task Activities for Phase I. The major evaluations in this program were performed in Tasks 3 and 4.

1. OVERVIEW OF MATERIALS ASSESSED

Two major types of epoxy-glass materials were evaluated in this program. These were the ultra-thin copper-clad laminates and the unclad additive-type laminates.

A review of the literature and a survey of laminators revealed that eight laminate types (epoxy-glass) existed that could be evaluated for this program. The materials fell into two major categories: ultra-thin copper-clad and unclad additive laminates. Currently, there are no approved specifications covering these materials.

Ultra-Thin Copper-Clad Laminates – Two types of ultra-thin copper-clad material, peelable and etchable, were available for evaluation. Both have an ultra-thin copper foil (1/8 oz/ft^2 or 5-micron copper thickness) overlaid or covered with a protective carrier metal. (See Figure 2.)

The peelable ultra-thin copper laminate has a 1-1/2 to 2-oz/ft^2 carrier copper foil applied to the ultra-thin copper. The carrier is attached by a proprietary process to the ultra-thin copper to effect a weak peelable bond. The peelable copper layer prevents oxidation, eliminates drill burring, and protects the thin copper from dents and scratches through the processing operations. After drilling and prior to electroless copper plating, the carrier foil is removed to expose the bright, clean surface of the thinner copper cladding and is processed immediately without need of prior deburring or cleaning steps. The copper carrier is salvageable.

The etchable ultra-thin copper laminate has a thin aluminum carrier attached to the copper to protect the copper surface. After drilling and prior to the processing for electroless copper plating, the aluminum surface is chemically removed to achieve the same benefits as those of the peelable type.

Unclad Laminates – The unclad laminates available for evaluation of semi-additive PWB construction are of three types: swell-and-etch, sacrificial foil, and adhesively coated.

One potential additive material of the swell-and-etch type is a bare epoxy-glass laminate with resin-rich surfaces. To ensure adequate electroless copper adhesion to the laminate, the epoxy "buttercoat" surface is exposed to an organic solvent (to cause softening and swelling of the resin) followed by a chromic-sulfuric acid treatment to condition the surface for electroless copper deposition. As discussed in the following topic, the swell-and-etch type was not evaluated.

Sacrificial foil material is an epoxy-glass laminate clad with anodized aluminum foil with the anodized surface bonded directly to the epoxy resin surface. After drilling and prior to electroless copper application, the aluminum foil is etched away leaving a replica of the anodized surface finish in the epoxy. The result is a highly textured surface that provides bonding sites for mechanical attachment of the electrolessly deposited copper.

The adhesive-coated epoxy-glass laminate is coated on both sides with a proprietary adhesive coating. After drilling and prior to electroless copper plating, the adhesive must be conditioned using chromic-sulfuric acid followed by neutralization in sodium metabisulfide solution.

The three additive laminate types previously described can be obtained either in the seeded or the nonseeded condition. Seeding consists of dispersing an electroless copper catalyst uniformly into the polymeric resin prior to the lamination process. A catalyst is also instituted in any adhesive coating used in the seeded type. Preliminary evaluation of seeded laminates resulted in rejection of this material type for this program because of low insulation resistance measurements before and after humidity. In addition, material

variability between suppliers was found and therefore the seeded laminates were dropped from the program.

Although MIL-P-13949 and MIL-P-55617 specifications have applicability to the qualification of materials for this program, there are no military documents specifically for the additive or ultra-thin copper-clad laminates. IPC-AM-361 is a proposed commercial specification for additive laminates, but was not utilized for this program.

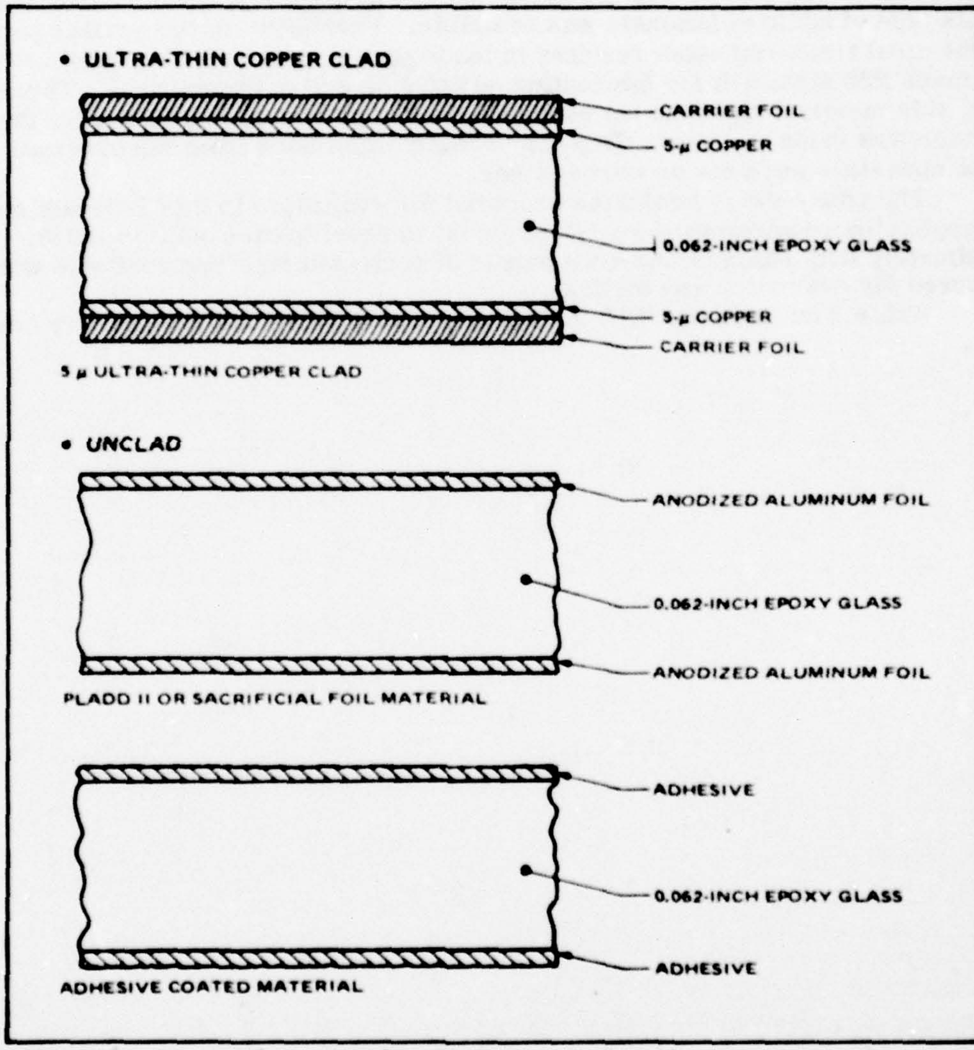


Figure 2. Types of Epoxy Glass Laminates Evaluated. Two types of carrier foil were used in this program – peelable and etchable.

2. PROCUREMENT OF TEST MATERIALS

A vendor survey produced nine sources for the needed materials. Approximately fifty panels of each available material type were procurred for evaluation.

Effort began with a review of the Qualified Products List for MIL-P-13949. Vendors from this list and other known vendors were contacted with regard to availability and cost of additive and ultra-thin copper type laminates. From these contacts nine sources were found, each of which indicated that one or more of the material categories could be supplied for this program.

It was subsequently discovered that the swell and etch additive technology for printed wiring boards was not being utilized by industry, and no assured source of this type of additive laminate was available. Variability in the surface produced by chemical treatment often resulted in inadequate copper adhesion (peel strength), and made this approach for fabricating additive circuitry impractical. Therefore, this material type was not procured for the program. Additionally, the decision was made earlier to drop the "seeded" laminates from the program, so these materials were not procured either.

The epoxy-glass laminates procured for evaluation in this program met the applicable requirements for GF material in specification MIL-P-13949. Approximately fifty 10x12x0.062-inch panels of each material type available was procured for evaluation and testing.

Table 2 outlines the PNB material sources, types and preliminary cost data.

TABLE 2. PWB MATERIAL SOURCES, TYPES AND COST

Available PWB materials: price/ft^2 (GF 0.062-inch thick)

	Additive laminates		Ultrathin copper foil laminates	
Vendor	Adhesive coated	Sacrificial foil	Peelable	Etchable
A	–	$2.51	$2.90	$2.90
B	–	–	$3.00	–
C	$3.10	$3.26	$3.75	$3.74
D	–	–	$4.08	–
E	–	$3.95	$3.95	$3.95
F	–	–	$3.45	$3.37
G	–	$5.58	$4.92	$3.12
H	$3.54	–	$3.65	$3.65
I	–	$2.32	$2.75	$2.88

Notes:

1/ Materials procured for evaluation in heavy outline.
2/ Prices are as of 2-25-77 for small procurements (≅ 100 panels).

3. FABRICATION OF TEST PANELS

Test panels for each vendor/material combination were prepared according to a previously documented process. A modified IPC pattern was applied to each.

Before any test panels could be fabricated for the screening test, processing documents were prepared for each of the four material types to be evaluated (adhesive coated, Pladd II, and the two types of ultra-thin copper-clad). This was to assure uniformity in processing and included the processes recommended by the vendors for the special treatments of the two unclad material types, namely, the adhesive-coated laminates requiring the chromic-sulfuric acid/neutralizer, and the Pladd II (sacrificial foil) laminates requiring the foil removal and adhesion promotion steps. These documents are listed in Appendix B-3 and were subsequently refined during Task 4. Also shown graphically in Figure 3 is a comparison of the semi-additive and ultra-thin copper-clad processes with the standard subtractive process.

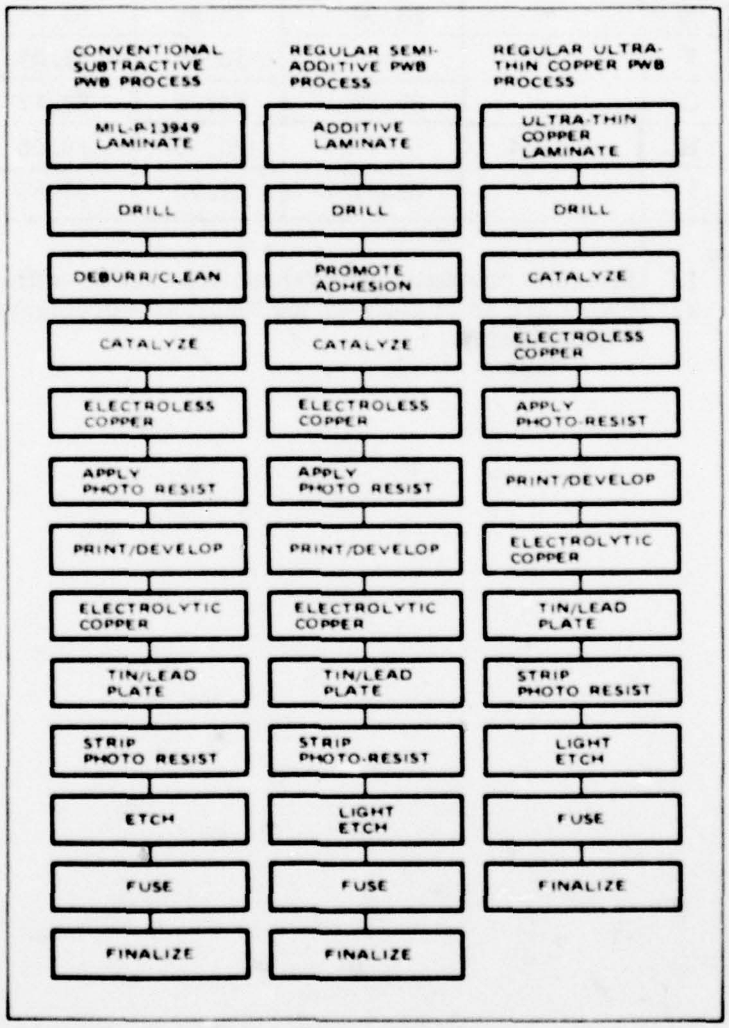


Figure 3. Comparison of Printed Wiring Board Processes. Most processing steps for the semi-additive and ultra-thin copper-clad processes are common to the subtractive process.

Four panels (10 x 12 x 0.062 inches) of each vendor/material combinations were fabricated using the Hughes-modified IPC test pattern shown in Figure 4, and in accordance with the above mentioned procedures.

A low rate electroless copper system followed by a pyrophosphate copper plating bath was used to produce the panels in this task (various other electroless systems were subsequently evaluated in a later task). All panels were plated with a 0.001-inch minimum of copper.

The Hughes-modified test pattern was chosen for use in all the screening tests in this program. The resultant test panels fabricated using this test pattern provides:

- Five groups of test tabs for peel strength determinations on each side of the panel
- Two IR patterns per panel side
- Four groups of plated-through-holes (PTHs) per panel side for continuity tests and PTH evaluation
- One area for volume resistivity measurements
- One area for solderability evaluations

The test procedure in Appendix B-1 describes in full detail the tests used in this program.

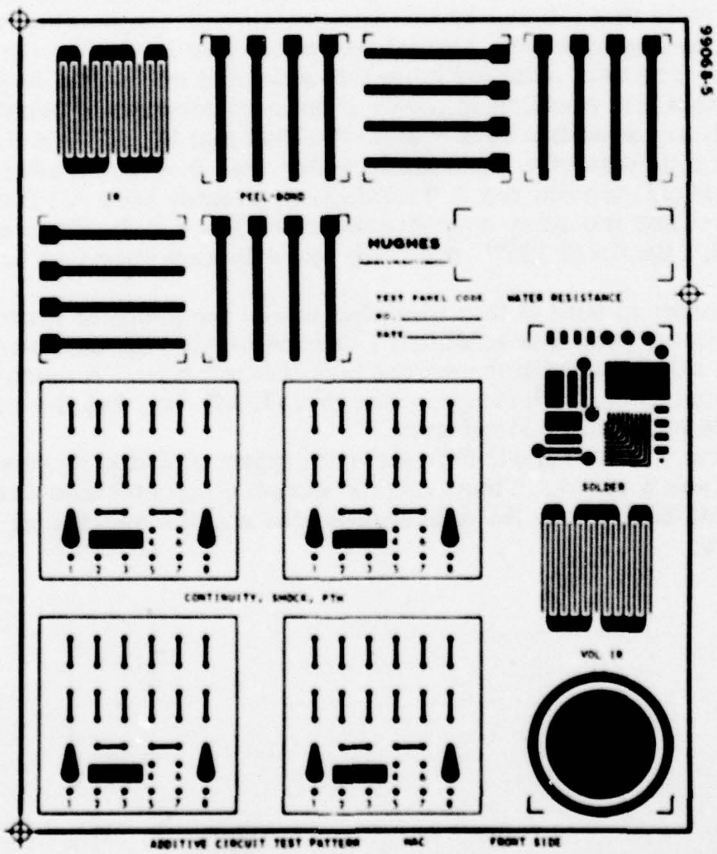


Figure 4. Modified IPC Test Pattern (Front Side Only Shown). This pattern provided coupons for the acceptance tests.

4. PRELIMINARY SELECTION AND TESTING OF CANDIDATE MATERIALS

The screening tests performed during Task 3 were visual, plating adhesion (tape test), peel strength, and warp and twist. Based upon results of the test data from a minimum of three test panels for each material/source type, four candidate materials were chosen for process evaluation in Task 4.

Hughes-Fullerton, as a member of the IPC additive round-robin test team, has gained considerable experience in the qualification of printed wiring boards manufactured by the additive and semi-additive processes. It was determined during the round-robin tests that peel-strength values after plating, solder float, thermal cycling, and at 125°C were indicative of the quality of the product. Values obtained could be related to laminate surface preparation, plating qualities, and the presence or absence of a plating post-bake cycle during the processing. Therefore, the screening tests performed during this task included the aforementioned peel-strength tests; plating adhesion using the standard adhesive tape test; and warp and twist measurements as described in the Test Plan (Appendix B-1).

The averaged results of these tests are listed in Table 3. All four material types (the adhesive coated, Pladd II, and both types of ultra-thin copper-clad laminates) passed the requirements of the test. In addition, each of the selected materials was fabricated into test panels and subjected to additional peel-strength testing to ensure against latent failures on Task 4 (Process Optimization). The data obtained from this extended effort (Table 4) indicated there was no apparent problem in meeting the peel-strength requirements of the applicable military specifications — MIL-P-13949 and MIL-P-55617. The peel strength of all four material types was greater than 8.2 lbs/in after solder float (military specification requires 8.0 minimum); greater than 8.1 lbs/in after temperature cycling (military specification specifies 8.0 lbs/in minimum); and greater than 6.1 lbs/in at 125°C (military specification specifies 5.0 lbs/in minimum).

It is worthy to note at this time that within the group of materials tested, the adhesive-coated laminate exhibited extraordinarily high peel-strength values ($\geq$ 17 lb/in) at all test conditions except high temperature. A much lower peel-strength resulted at the high temperature test (7.5 lb/in), but the results were still acceptable by military standards.

From these results, all four material types qualified as candidate systems for the Task 4 effort. These are the peelable and etchable carrier ultra-thin copper-clad laminates, the adhesive-coated and the sacrificial foil (Pladd II) unclad liminate.

TABLE 3. MATERIAL SCREENING TEST RESULTS

The results listed are the average values obtained from three test panels from each vendor.

Material Type \ Tests	Vendor	Peel Strength – lbs/in As Received	Peel Strength – lbs/in After Solder	Visual	% Warp and Twist	Adhesion
Ultra-thin Cu-clad-peelable carrier	A	8.2	8.7	Good	3.5	Accept
	G	8.3	8.8	Good	0.7	Accept
	I	7.9	8.2	Good	2.0	Accept
Ultra-thin Cu-clad-etchable carrier	A	7.2	7.4	Good	1.3	Accept
	F	7.8	6.2	Good	3.4	Accept
	I	8.9	10.7	Good	1.6	Accept
Unclad laminate – adhesive coated	C	18.1	20.6	Good	2.8	Accept
	H	16.7	17.1	Good	1.9	Accept
Unclad laminate – sacrificial foil	A	10.0	8.7	Good	2.3	Accept
	I	10.1	8.6	Good	2.1	Accept

TABLE 4. EXTENDED PEEL STRENGTH RESULTS OF CANDIDATE MATERIALS

Material Information		Determined Peel Strength, lbs/in. of Width			
Vendor	Laminate Description	At Room Temp	After Solder Float	At 125°C Temperature	After Temperature Cycling
I	Ultra-thin copper clad, peelable carrier	7.9	8.2	6.4 −0.5 ±0.3	8.1 −0.2 +0.2
I	Ultra-thin copper clad, etchable carrier	8.9	10.7	8.1 −1.0 +0.5	8.7 −0.5 +0.4
C	Unclad laminate – Adhesive coated	18.1	20.6	7.5 −2.2 +3.1	17.2 −0.1 +0.1
A	Unclad laminate – Sacrificial foil	10.0	8.7	6.1 −0.4 +0.6	10.7 −1.6 +1.1
MIL-P-13949 Requirements (Minimum requirements for 1 oz/ft^2 copper)		No Requirement	8.0 (6.0)*	5.0 (5.0)	8.0 (6.0)

All average values based on at least 3 test results from 4 individual test panels. All tests performed from plated copper = 1 oz/ft^2.

*MIL-P-55617 requirements in parentheses.

1. OVERVIEW OF EVALUATION AND OPTIMIZATION OF PROCESSES

PWBs using ultra-thin copper-clad materials were fabricated by the standard subtractive process while unclad materials were processed per the vendors' recommendations. After evaluation, the processes were optimized and test boards were fabricated and tested for conformance to the appropriate military specifications.

At the beginning of the program, several areas were anticipated to be potential problems. As an example, the removal of drilled-hole burrs was expected to result in an investigation of drill geometry, drill speeds and feeds, and drill backup boards.

During the past several years, however, the Hughes-Fullerton Manufacturing Division has been studying methods for eliminating drill-hole burrs in copper-clad materials. It was found that overlaying the copper-clad laminate with 0.005-inch-thick aluminum foil prior to drilling would eliminate burrs. This technique was put into effect just as the MM&T program was awarded, and its incorporation into the program at the outset resolved this potential problem area.

A second area of possible investigation pertained to surface characteristics of additive laminates. Peel strengths have been chosen as important criteria in qualifying an optimum process. Peel strength as related to plating adhesion is affected by the laminate surface condition. It was planned that scanning electron microscope (SEM) examination of surfaces would be performed to correlate visual surface appearance and adhesion.

The question arises as to how one determines the adhesion characteristics of an ultra-thin copper-clad material when only the copper laminate interface characteristics relate to adhesion. In its experience with thin-foiled laminates, Hughes-Fullerton had demonstrated that copper plating the 5-micron copper to a 1-oz/ft^2 weight (0.0014 inch thick) permits an evaluation of peel strength. Accordingly, the 1-oz/ft^2 peel strength criteria of MIL-P-13949 and MIL-P-55617 would be applicable. Other areas requiring investigation were discovered, such as the effect of electroless copper catalyst size on the nature of electroless copper deposition and its resulting peel strength, and the failure of adhesively coated laminates to pass insulation resistance (500 megohms, minimum) during humidity exposure.

After investigating and solving these specific problems, the applicable processes for fabrication were optimized. Using the candidate materials chosen during Task 3, five test panels of each type were fabricated and qualified to the applicable portions of the military specifications (Table 5). These military documents are identified in Appendix A-2. Testing was performed in accordance with the Test Plan.

TABLE 5. QUALIFICATION TESTS

Examination or Test	Applicable Specification
1. Visual examination	MIL-P-55110
2. Warp and twist	
Warp, %	(None)*
Twist, %	(None)*
3. Plating adhesion	MIL-P-55110
4. Plating characteristics	
Conductor thickness, inches	(None)*
PTH wall thickness, inches	MIL-STD-275
Ratio thickness (Cond: PTH wall)	(None)*
PTH cross-section quality	MIL-P-55640
5. Peel strength, lb/in. of width	
As received (initial)	(None)*
After thermal stress	MIL-P-13949
After thermal cycling	MIL-P-13949
At 125^{o}C	MIL-P-13949
6. Continuity (thermal shock)	
Resistance variance, % (maximum)	MIL-P-55110
Post thermal shock appearance	MIL-P-55110
7. Dielectric strength (30 kV min)	
Prior to humidity exposure	MIL-P-55110
After humidity exposure	MIL-P-55110
8. Insulation resistance, ohms	
Prior to humidity exposure	MIL-P-55110
At 5th cycle	MIL-P-55640
At 10th cycle	MIL-P-55640
9. Surface and volume resistivity	
Volume resistivity (megohm-CM)	MIL-P-13949
Surface resistivity (Megohm)	MIL-P-13949
10. Bond strength	
2000 PSI tensile stress test	MIL-P-55110
Appearance after test	MIL-P-55110
11. Solderability	MIL-P-55110**
Visual Quality	IPC-S-801
12. Water absorption, %	MIL-P-13949

*No military requirement
**Requirement only if specified in contract or P. O.

2. SURFACE CHARACTERISTICS OF LAMINATES

Examination by the scanning electron microscope (SEM) indicated that the ultra-thin copper-clad material exhibited a surface roughness comparable to that of 1-oz/ft^2 copper-clad material. Both unclad laminates, after surface conditioning, exhibited a surface roughness suitable for electroless copper bonding.

Each of the four laminate type materials was prepared for surface examination using the SEM. The copper foil was removed from the ultra-thin copper-clad materials (peelable and etchable types) as well as from a sample of standard MIL-P-13949 1-oz/ft^2 clad laminate. The purpose of this task was to examine the texture of the epoxy butter coat to determine the amount of surface roughness on the copper foil and correlate this to the peel-strength values for both the candidate materials and the 1-oz/ft^2 material. Of the unclad laminate materials, the adhesive-coated laminate was chemically treated using chromic-sulfuric acid solution and neutralized in the sodium metabisulfite solution. The foil was etched away from the Pladd II type material (sacrificial foil type) and the laminate processed through the surface conditioner prior to the SEM examination.

The results of the SEM examination are illustrated in Figures 5 and 6. The texture of the dielectric (epoxy) surfaces of MIL-P-13949 standard 1-oz/ft^2 material can be compared with the surfaces of the two types of ultra-thin copper-clad laminate, as well as the adhesive coated and the sacrificial foil laminates. The photographs, at 500 to 15000 times magnification, give a partial understanding of the relative peel strength qualities obtained by the various laminates. In the case of the copper-clad laminates, Figure 5a and 5b, the resulting peel strengths are a product of the "tooth" or surface roughness of the copper-foil treatment. Logically, it was believed the heavier weight foil, which sustains a greater "tooth" because of its thickness, would yield higher peel strength values. Surprisingly, the ultrathin (5-micron) copper laminates did meet MIL-P-13949 minimum peel strength requirements (i.e., 8 lb/in. after solder float). Photographs of these magnified surfaces are also shown in Figures 5c through 5f.

The adhesively coated additive laminates produced surfaces, after solution treatment, that understandably yielded extremely high peel strength (15 lb/in. minimum after solder float). The photographs of the magnified surface reveal random dispersion of small and large crevices that are conductive to mechanically "locking in" of the applied electroless copper (Figures 6a and 6b). The sacrificial aluminum foil additive laminate system, on the other hand, shows an entirely different surface structure, which is finer, more uniform, and not as deep in penetration (Figures 6c and 6d). Perhaps the only reason that this "mud flat" texture achieves 11 lb/in. minimum, (solder float) peel strengths is due to the relatively high surface area – a replica derived from the anodized surface of the sacrificial foil.

The results obtained from the SEM examination of laminate surfaces confirms the reports of other investigators (9, 38 of Appendix A-1), and consolidates the observations for the four dielectrics in one publication.

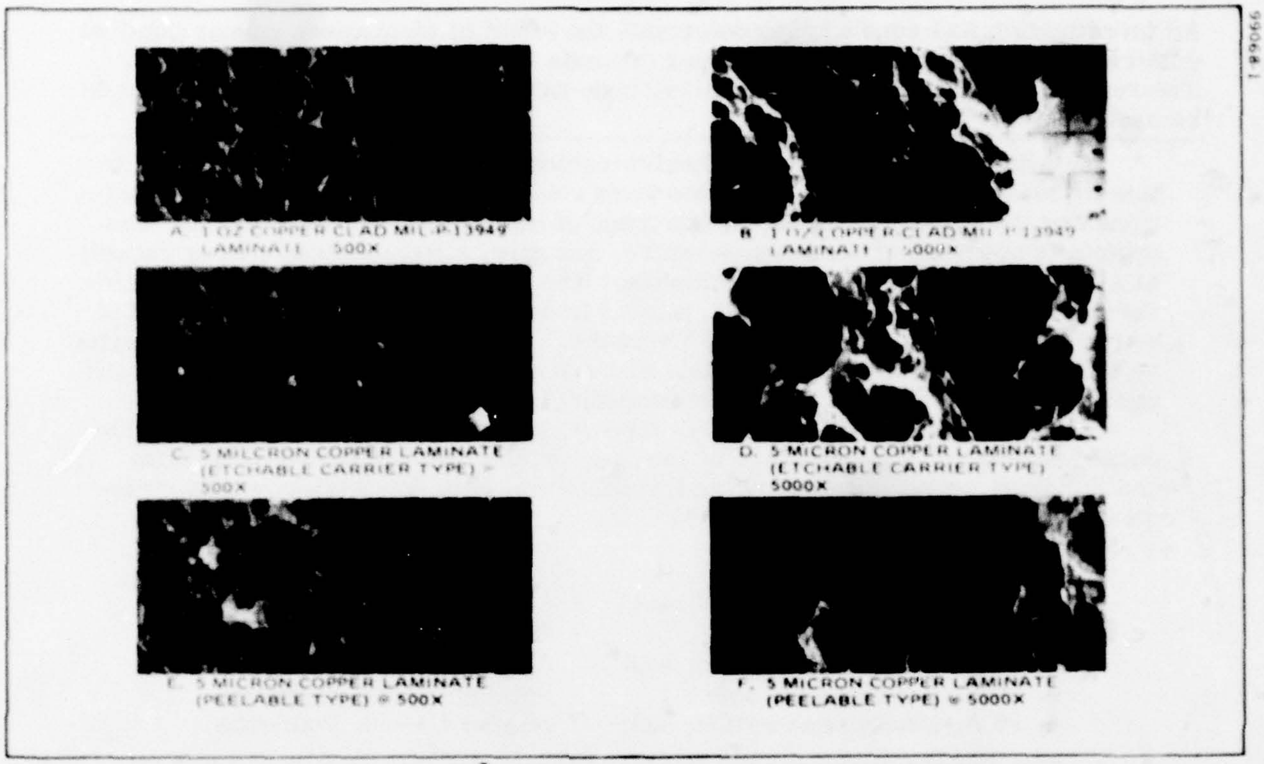


Figure 5. SEM Photographs of 1 oz/ft^2 and Ultra-Thin Copper Clad Laminate Surfaces After Copper Removal. The surface roughness of the ultra-thin copper clad material is similar in texture to that of the standard 1 oz/ft^2 material.

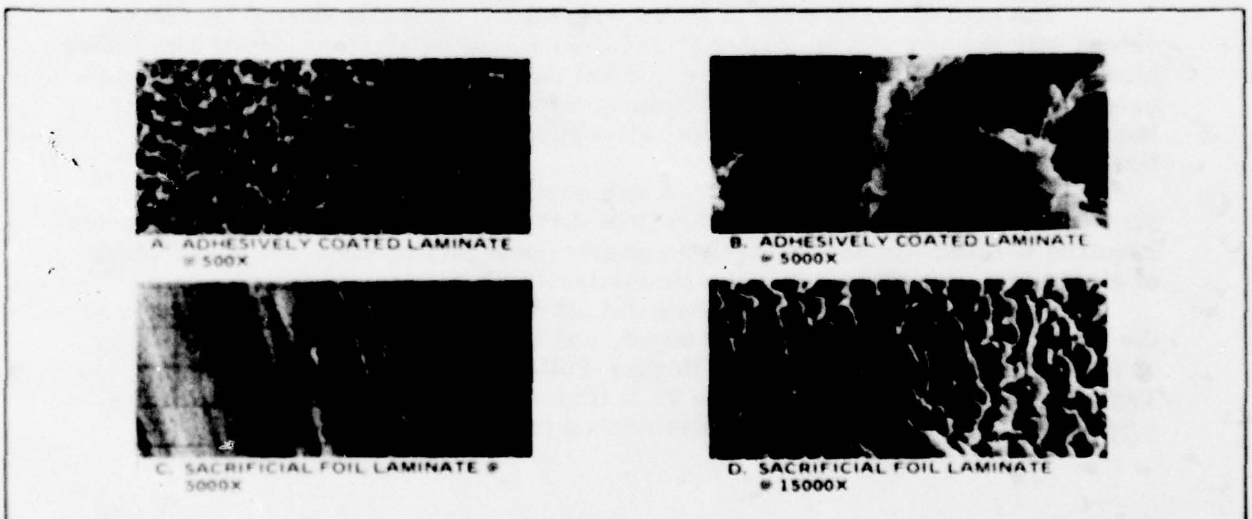


Figure 6. SEM Photographs of Additive Laminate Surfaces Prior to Electroless Copper Deposition. The surface roughness produced in the adhesive coating by the chromic/sulfuric acid treatment are conducive to good copper bonding while the finer "mud flat" texture of the sacrificial foil laminate is a replica of the anodized aluminum foil surface.

3. EFFECT OF ELECTROLESS COPPER CATALYST ON PEEL STRENGTH

An investigation was conducted to determine the effect of electroless copper catalyst particle size on peel strengths of copper deposits on additive laminate materials. The results showed that the 50 Å catalyst/high-rate electroless copper system could be used for PWB fabrication.

Both sacrificial foil and adhesive-coated additive laminates were used in this investigation. These dielectrics were subjected to acid or salt catalyst solutions and then plated using one of two types of electroless copper systems. One system is operated at room temperature, and gives a fine-grained copper deposit at a rate of 30 microinch per 30 minutes. The other system, operated at an elevated temperature (100° - 120°F), results in a coarse-grained copper deposit at a rate of 70-100 microinches per 30 minutes. Catalyst particle size was reported by the formulators to contain particle sizes of either 30-50 Å or 3000-5000 A and could be categorized in that manner accordingly.

Possible catalyst/electroless copper systems shown in Table 6 were discussed with suppliers. Because of the large number of possible combinations and the short time available for the investigation, only five systems were evaluated. These systems were the following.

Catalyst	Electroless Copper
• 3000-5000 Å, Shipley 6F, acid	Shipley 328S, low-rate
• 50 Å, Enthone 443, acid	Shipley 328S, low-rate
• 50 Å, MacDermid 9070M, salt	Shipley 328S, low-rate
• 50 Å, Enthone 443, acid	Shipley CP-74, high-rate
• 50 Å, MacDermid 9070M, salt	Shipley CP-74, high-rate

The derived peel strength results of the evaluation given in Table 7 are the averages for the minimum values of 12 individual tests in each case. Maximum values (not indicated herein) were frequently 4 to 5 lb/in. of width greater than the average minimum values reported.

The peel strength tests of the sacrificial foil material showed increased values with the use of the smaller 50 Å (acid or salt) catalyst employed with either electroless copper type system, i.e., a low rate of deposition, fine-grained copper or a high rate of deposition, coarse-grained copper. The adhesive-coated laminates, however, gave better peel strengths with a 50 Å (salt) catalyst/fine-grained copper system.

Based on the fact that the 50 Å salt catalyst resulted in the greatest improvement in peel strength (up to 70%) and that a high-rate electroless copper was required to eliminate any electrolytic copper panel plating step, the initial choice of electroless system was a 50 Å salt catalyst/high-rate combination.

However, because the test data did not disclose appreciable differences in the results for 50 Å acid or salt catalyst, and because of the current availability of electroless copper baths within Hughes-Fullerton, the system used for the Task 4 evaluation test panels was a 50 Å acid catalyst/high-rate coarse-grained copper system that deposited 70 microinches (minimum) within 30 minutes.

TABLE 6. ELECTROLESS COPPER AND CATALYST SYSTEMS SURVEYED

Electroless Coppers

- Low-Rate Deposition
  - Chemline – Copperdep 400
  - Enthone – 404 and 405
  - MacDermid – 9027S
  - Oxy Metal – Oxytron CU500
  - Shipley – 328S
- High-Rate Deposition
  - Chemline – Copperdep 420
  - Enthone – 10225, 02204, and 01015R
  - MacDermid – 9055 and 9048
  - Oxy Metal – Oxytron CU510
  - Shipley – CP-74

Catalyst Systems

- Acid
  - Chemline – Adion 550
  - Enthone – 443
  - MacDermid – 9070
  - Oxy Metal – Oxytron 301
  - Shipley – 6F and 9F
- Salt
  - Chemline – Adion 230
  - MacDermid – 9070M
  - Shipley – Cataposit 44

TABLE 7. PEEL STRENGTH RESULTS OF ELECTROLESS COPPER/CATALYST EVALUATION (RESULTS ARE IN LBS/IN. OF WIDTH)

Catalyst Type and Size / Electroless Copper Type	Acid 3000-5000 Å		Acid 50 Å				Salt 50 Å			
	As Plated	After Solder	As Plated	After Solder	After Temp	At Temp	As Plated	After Solder	After Temp	At Temp
Sacrificial Foil										
Low Rate (Fine Grain)	10.16	8.68	14.31	13.38	15.41	7.73	13.45	14.81	14.60	6.18
High Rate (Coarse Grain)	-	-	12.58	13.74	15.16	6.88	16.10	14.89	15.09	7.83
Adhesively Coated										
Low Rate	16.52	16.74	18.70	18.53	20.07	11.63	19.02	19.04	20.69	11.09
High Rate	-	-	13.06	15.50	13.18	8.25	8.32	6.46	-	6.92

4. THE PROBLEM OF INSULATION RESISTANCE ON ADHESIVE-COATED BOARDS

PWBs fabricated with the adhesive-coated, unclad material failed to pass the insulation resistance test after exposure to humidity. This problem was eliminated by dissolving and removing the adhesive with a flourocarbon/methylene chloride (FC/TMC) solvent as the final step in fabrication.

The effect of humidity on insulation resistance properties of adhesive-coated material was investigated after two groups of test panels failed this test. The vendor of the adhesive-coated material believes that the conditioned adhesive layer present between conductors might be entrapping ionic contaminants contributing to the low insulation resistance values (<500 megohms). It was suggested that this adhesive layer be removed to improve the insulation resistance values.

The investigation of insulation resistance improvement consisted of the use of an alkaline permanganate solution to etch away the adhesive coating between the circuits, and conformally coating the test panels with a MIL-I-46058 polyurethane prior to exposure to any humidity. It was found that the use of alkaline permanganate did not improve the insulation resistance of either the solder-coated or copper (only) circuits. Two separate sets (four specimens each) of conformally coated test specimens resulted in acceptable insulation resistance values under humidity conditions performed in accordance with the test procedure (refer to Appendix B-1 for details).

Because the conformally coated test specimens were subjected to an extensive and thorough cleaning procedure not normally imposed on the conventional insulation resistance specimens, it was decided to check the insulation resistance after the cleaning operation but without the conformal coating. These specimens passed the insulation resistance tests during humidity exposure, indicating that the cleaning process, and not the conformal coating, improved the insulation resistance.

A second group of test specimens, cleaned and tested in the same manner, verified the prior results. The cleaning procedure employed for this investigation was as follows:

1. Immerse in FC/TMC for 3 minutes.
2. Air dry.
3. Immerse for 30 seconds in dionized water containing 0.01-0.05 percent Triton X-100 wetting agent.
4. Rinse in dionized water for 30 seconds.
5. Rinse in second dionized water for 30 seconds.
6. Rinse in isopropyl alcohol for 30 seconds.
7. Air dry.

Insulation resistance values obtained are summarized in Table 8.

From the results of the evaluation it was postulated that the FC/TMC solvent (liquid phase) had removed the exposed adhesive coating between conductors and thereby eliminated a deleterious characteristic of the adhesive which had contributed to unacceptable insulation resistance results. Post-cleaning microscopic examinations of the test specimens revealed the absence of adhesive between circuits and thereby confirmed the initial assumption.

The effect of the solvent on the adhesive became a primary concern. Prior tests had been conducted evaluating the effect of FC/TMC vapors on the adhesive surface of the laminate (as might occur during a normal PWB vapor cleaning operation). The results, as listed in Table 9, indicate no harmful effects by the FC/TMC vapors on the adhesive surface of the PWBs.

However, it was quite evident that FC/TMC in the liquid state produced a different phenomenon. To verify whether this aggressive solvent would have any

adverse effect on the adhesive under the conductors (thereby reducing the peel strength characteristics), several additional test specimens were fabricated from the adhesively coated material. Samples were cleaned using the liquid FC/TMC solvent and were submitted for peel strength evaluations. In all cases the peel strength was over 16 lb/inch of width, thus indicating that the liquid solvent treatment did not adversely affect the peel strength. In addition, no degrading of the solderability was detected through use of the previously described adhesive removal process, which could have redeposited traces of the adhesive on the tin-lead-coated conductor surfaces.

TABLE 8. INSULATION RESISTANCE OF ADHESIVELY COATED TEST SPECIMENS (Not conformally coated)

When Measured	Before Cleaning (ohms)				After FC/TMC Cleaning (ohms)			
Prior to humidity	∞	∞	∞	∞	15G	16G	18G	20G
At 5th cycle	short	5 M	11 K	8 K	70G	80G	30G	40G
At 10th cycle	-	short	short	short	70G	90G	40G	70G

TABLE 9. EFFECT OF EXPOSURE TO FC/TMC VAPORS ON ADHESIVELY COATED MATERIAL

Test Condition	Number of Exposure Cycles*	Average Weight Change, % (6 specimens)
As received	6	+0.19
After adhesive conditioning	6	-0.03
After adhesive conditioning, Electroless copper deposition and etching	6	+0.06

*30 seconds in vapor + 1-hour air dry + 24 hours in desiccator = 1 cycle.

5. EVALUATION AND OPTIMIZATION OF PROCESSES

Five test panels of each material type were fabricated and subjected to the test requirements of MIL-P-55110 and MIL-P-55640. All four material types passed the test requirements.

The objective of this task was to fabricate at least five PWB test panels of each material type using the modified IPC test pattern. These PWBs would then be subjected to the tests outlined and described in the Test Procedure (Appendix B-1). These tests include visual examination, warp and twist, plating adhesion, PTH examination, peel strength, thermal shock, insulation resistance (after humidity exposure), dielectric strength, surface and volume resistivity, and bond strength of PTH.

One material at a time was processed beginning with the ultra-thin peelable type followed by the ultra-thin etchable, and sacrificial foil, and finally the adhesively coated laminate. The test panels were processed using the electroless copper system established in the previous task, i.e. a 50 Å acid catalyst in conjunction with an elevated-temperature, high-speed electroless copper bath. In addition, the process instruction for each of the laminate types was upgraded and optimized prior to the fabrication of the test panels. These are listed in Appendix B-3, and include the previously discussed adhesive removal treatment in FC/TMC solvent for the adhesive coated laminates. All the panels were electroplated with copper in a pyrophosphate solution and standard tin-lead plating and fusing techniques were employed. Processes were designed to provide the following minimum thicknesses: electroless copper, 70 microinch; electrolytic copper in PTH, 0.001 inch; tin-lead, 0.0003 inch.

At least five test panels were fabricated from each of the candidate materials. Four of the five panels were used for the evaluation testing and the fifth panel was reserved for reference purposes.

The tests to evaluate the optimized processes were performed in accordance with the Test Procedure (Appendix B-1). Two hundred seventy-six individual tests were performed to quality each candidate system. All four material types passed the requirements of the Test Plan and therefore PWBs fabricated using these four material types would be acceptable to the military specifications.

A summary of the test results appears in Table 10, and a complete listing of the test results is included in Appendix B-5.

TABLE 10. PROCESS EVALUATION AND DEVELOPMENT OF OPTIMIZED PROCESSES

EXAMINATION OR TEST	APPLICABLE SPECIFICATION	ULTRA-THIN COPPER-CLAD LAMINATE TYPES		ADDITIVE LAMINATE TYPES	
		PEELABLE CARRIER (AVERAGE VALUES) ••	ETCHABLE CARRIER (AVERAGE VALUES) ••	SACRIFICIAL FOIL (AVERAGE VALUES) ••	ADHESIVELY COATED (AVERAGE VALUES) ••
VISUAL EXAMINATION	MIL-P-55110	PASS	PASS	PASS	PASS
WARP AND TWIST					
WARP, %	(NONE) •	3.5	4.6	1.6	0.9
TWIST, %	(NONE) •	3.8	2.9	1.0	0.7
PLATING ADHESION	MIL-P-55110	PASS	PASS	PASS	PASS
PLATING CHARACTERISTICS					
CONDUCTOR THICKNESS, IN.	(NONE) •	0.0023	0.0018	0.0022	0.0016
PTH WALL THICKNESS, IN.	MIL-STD-275	0.0021	0.0016	0.0023	0.0015
RATIO THICKNESS (COND: PTH WALL)	(NONE)	1.09	1.11	0.97	1.15
PTH CROSS-SECTION QUALITY	MIL-P-55640	PASS	PASS	PASS	PASS
PEEL STRENGTH, LBS/IN. OF WIDTH					
AS RECEIVED (INITIAL)	(NONE) •	7.4	8.7	12.5	16.8
AFTER THERMAL STRESS [8 LBS MIN]	MIL-P-13949	9.7	9.5	14.3	16.3
AFTER THERMAL CYCLING [8 LBS MIN]	MIL-P-13949	8.4	8.3	12.5	15.5
AT 125°C [5 LBS MIN]	MIL-P-13949	9.5	10.4	6.5	9.1
CONTINUITY (THERMAL SHOCK)		PASS	PASS	PASS	PASS
RESISTANCE VARIANCE [10% MAXIMUM]	MIL-P-55110	6.1	6.4	3.3	2.8
POST THERMAL SHOCK APPEARANCE	MIL-P-55110	PASS	PASS	PASS	PASS
DIELECTRIC STRENGTH [30 KV MINIMUM]					
PRIOR TO HUMIDITY EXPOSURE	MIL-P-55110	PASS	PASS	PASS	PASS
AFTER HUMIDITY EXPOSURE	MIL-P-55110	PASS	PASS	PASS	PASS
INSULATION RESISTANCE [5×10^8 Ω MIN]					
PRIOR TO HUMIDITY EXPOSURE	MIL-P-55110	25.6×10^{12}	25×10^{12}	2×10^{11}	17.2×10^{12} †
AT 5TH CYCLE	MIL-P-55640	52.3×10^9	15×10^9	2.2×10^{10}	56×10^{10} †
AT 10TH CYCLE	MIL-P-55640	36.6×10^9	8×10^9	2×10^{10}	67.5×10^{12} †
SURFACE AND VOLUME RESISTIVITY					
VOLUME RESISTIVITY [10^6 MΩ-CM MIN]	MIL-P-13949	23.6×10^{10}	4.5×10^8	34×10^9	8.1×10^{10} †
SURFACE RESISTIVITY [10^4 MΩ MIN]	MIL-P-13949	57.0×10^4	6.9×10^5	21×10^5	1.8×10^4 †
BOND STRENGTH					
TENSILE STRESS TEST [2000 PSI MIN]	MIL-P-55110	PASS	PASS	PASS	PASS
APPEARANCE AFTER TEST	MIL-P-55110	PASS	PASS	PASS	PASS
SOLDERABILITY	MIL-P-55110 •				
VISUAL QUALITY	IPC-S-801	PASS	PASS	PASS	PASS
WATER ABSORPTION, % [0.35% MAX]	MIL-P-13949	0.14	0.10	0.13	0.19

• NO REQUIREMENT OR ONLY WHEN SPECIFIED

† INITIALLY FAILED WITHOUT FC/TMC CLEANING

•• AVERAGE OF RESULTS FROM 4 TEST PWBs DERIVED FROM 276 INDIVIDUAL TESTS PERFORMED ON EACH CANDIDATE/PROCESS SYSTEM

9068-11

1. PRELIMINARY COST ANALYSIS OF THE FABRICATION PROCESS

All of the material types except the sacrificial foil were more expensive than the standard *0.062 inch-thick* MIL-P-13949, 1 *oz/ft²* material. However, an approximate nine percent labor saving was realized by a modified all-copper process using solder coating/air leveling (SCL) equipment.

The objective of this task was to obtain data relative to the cost of fabricating PWBs using the best of the ultra-thin clad or additive materials and related processes. The results from Task 4 clearly indicate that all evaluated, optimized systems meet the requirements of MIL-P-55110, and that any of the technologies could be chosen for cost analysis purpose.

Labor Costs – A preliminary cost analysis of the fabrication process was performed employing one of the ultra-thin copper-clad and one of the additive laminates. The compilation of data from this effort is given in Tables 11 and 12, which compare the standard subtractive process to the regular and modified PWB processes.

In the modified PWB process, all-copper circuits are produced by plating a heavier thickness of copper (0.002 inch) onto the board in the circuit pattern areas and the PTHs. However, the boards are not tin-lead plated, but are flash etched instead to remove the ultra-thin copper foil and 70 to 100 microinches of electroless copper in the unwanted areas. This flash etching technique also removes copper from the circuit traces and the PTHs, but because 0.002 inch of copper was plated in these areas, the resultant thickness of copper after the flash etch meets the specification requirement of 0.001/inch minimum. Therefore, this method of producing all-copper circuits lends itself to the use of solder coater/air leveling equipment (SCL) for the application of solder to the circuitry and PTHs. This results in a cost-effective method of producing solder-coated PWBs as shown in the labor comparison charts (Tables 11 and 12).

The labor-related time standards listed are used for general manufacturing cost evaluations. In both analyses, the modified processes (all-copper circuitry subsequently solder-coated) indicated an approximate 9-percent reduction in labor, the area in which major savings were identified.

Although not incorporated into the previously described cost data, an appreciable savings can be realized in increased yields (3 to 5 percent) and reduced etchant material needs (1/8 the cost as related to 1 oz copper). Laminate material costs were not incorporated because it is anticipated that future laminate costs will be comparable (or lower) in price than those for the subtractive material. Other cost factors involved (power, other chemicals, salvage, etc.) were determined to be insignificant for use in this initial cost projection.

The semi-additive and ultra-thin copper-clad processes also reflect the following intrinsic benefits that are difficult to equate monetarily: higher density design capabilities; increased rework probability after plating, especially with the unclad materials; and fewer environmental pollution problems.

TABLE 11. LABOR COMPARISON FOR PWB FABRICATION USING ULTRA-THIN COPPER-CLAD MATERIAL

Standard Subtractive PWB Process		Regular Ultra-Thin Copper PWB Process		Modified Ultra-Thin Copper PWB Process	
Process	Time Standard	Process	Time Standard	Process	Time Standard
1. Drill	0.340	1. Drill	0.340	1. Drill	0.340
2. Deburr and Clean	0.022	2. Catalyze	0.060	2. Catalyze	0.060
3. Catalyze	0.060	3. E-Copper	0.040	3. E-Copper	0.040
4. E-Copper	0.040	4. Apply Resist	0.068	4. Apply Resist	0.068
5. Apply Resist	0.068	5. Print/ Develop	0.200	5. Print/ Develop	0.200
6. Print/ Develop	0.200	6. Copper Plate	0.028	6. Copper Plate	0.028
7. Copper Plate	0.028	7. Tin/Lead Plate	0.028	7. Strip Resist	0.068
8. Tin/Lead Plate	0.028	8. Strip Resist	0.068	8. Light Etch	0.020
9. Strip Resist	0.068	9. Light Etch	0.020	9. Solder Coat/ Air Level	0.020
10. Etch	0.020	10. Fuse	0.060	10. Finalize	0.066
11. Fuse	0.060	11. Finalize	0.066		
12. Finalize					
Total	1.000	Total	0.978	Total	0.910

TABLE 12. LABOR COMPARISON FOR PWB FABRICATION USING SACRIFICIAL FOIL MATERIAL

Standard Subtractive Process		Regular Process		Modified Process	
Process	Time Standard	Process	Time Standard	Process	Time Standard
1. Drill	0.340	1. Drill	0.340	1. Drill	0.034
2. Debur and Clean	0.022	2. Etch Carrier	0.020	2. Etch Carrier	0.020
3. Catalyze	0.060	3. Catalyze	0.060	3. Catalyze	0.060
4. E-Copper	0.040	4. E-Copper	0.040	4. E-Copper	0.040
5. Apply Resist	0.068	5. Apply Resist	0.068	5. Apply Resist	0.068
6. Print/ Develop	0.200	6. Print/ Develop	0.200	6. Print/ Develop	0.200
7. Copper Plate	0.028	7. Copper Plate	0.028	7. Copper Plate	0.028
8. Tin/Lead Plate	0.028	8. Tin/Lead Plate	0.028	8. Strip Resist	0.068
9. Strip Resist	0.068	9. Strip Resist	0.068	9. Light Etch	0.020
10. Etch	0.020	10. Etch	0.020	10. Solder Coat/ Air Leveler	0.020
11. Fuse	0.060	11. Fuse	0.060	11. Finalize	0.066
12. Finalize	0.066	12. Finalize	0.066		
Total	1.000	Total	0.998	Total	0.930

1. PRELIMINARY COST ANALYSIS OF THE FABRICATION PROCESS (Continued)

Material Costs – The costs of the laminate materials are listed in Table 13 and are the result of responses from five vendors on quantities to 200,000 square feet. Alos listed in Table 13 for comparative purposes is the cost for similar quantities of 0.062-inch-thick MIL-P-13949, 1 oz/ft^2 copper-clad GF material presently used with the subtractive process. Currently, the costs of ultra-thin copper clad and adhesively coated laminates are somewhat higher than comparable 1 oz/ft^2 material, whereas the sacrificial foil laminate costs are somewhat lower. Conceivably, an increase in material demand due to any volume production of boards from this methodology will result in subsequent lower laminate costs brought about by competitive pricing.

TABLE 13. QUANTITY PRICE DATA OF LAMINATES FOR COST ANALYSIS EVALUATION

Supplier Code/	Quantity (x 10^3 sq ft)	Laminate Type (Unseeded 0.062-inch Thick, GF MIL-P-13949 Dielectric)				
		Semi-Additive		Ultra-Thin Foil Clad		1 oz/ft^2 Copper Clad *
		Sacrificial Foil	Adhesively Coated	Peelable	Etchable Carrier	MIL-P-13949/4
A	<10	$2.51	-	$2.90	$2.90	-
	10	2.58	-	2.72	2.68	-
	50	2.25	-	2.64	2.64	-
	100	2.23	-	2.60	2.56	-
	200	2.23	-	2.60	2.56	-
C	<10	3.26	3.10	3.75	3.75	-
	10	2.83	2.66	3.43	3.43	-
	50	2.83	2.62	3.43	3.43	-
	100	2.62	2.43	3.18	3.43	-
	200	2.62	2.43	3.18	3.18	-
E	<10	3.95	-	3.95	3.95	-
	10	3.00	-	3.10	3.10	2.24**
	20	3.00	-	3.10	3.10	2.24
	50	3.00	-	3.10	3.10	2.24
	100	3.00	-	3.10	3.10	2.24
	200	3.00	-	3.10	3.10	2.24
H	<10	-	3.54	3.65	3.65	-
	10	-	2.49	2.77	3.20	-
	50	-	2.49	2.77	3.20	-
	100	-	2.49	2.77	3.20	-
	200	-	2.49	2.77	3.20	-
I	<10	2.32	-	2.90	2.90	-
	10	2.09	-	2.80	2.80	-
	50	2.09	-	2.80	2.80	-
	100	2.09	-	2.80	2.80	-
	200	2.09	-	2.80	2.80	-

* Included for price comparison.
** Based upon large quantity purchase by Hughes.

SECTION 3
PHASE II – PRODUCTION IMPLEMENTATION

Section 3 – Phase II – Production Implementation

1. OVERVIEW OF PHASE II TASKS

Verification of the processes for PWB fabrication using ultra-thin copper-clad material was accomplished in a pilot production line environment. PWBs fabricated in this line where routinely tested and qualified to the requirements of MIL-P-55110B.

The Phase II portion of the program was devoted to the optimization and verification of the selected PWB fabrication process. This was accomplished in a pilot production facility designed, established and qualified for this purpose. In addition, a design package for an automated production line was made and delivered to MIRADCOM. Phase II tasks are summarized in Table 14.

Therefore, in the initial task, the optimized process from Phase I was upgraded and then verified by routinely fabricating PWBs from the ultra-thin copper-clad material and qualifying these boards to the applicable military specification requirements.

Another task consisted of the detailed design of a MIRADCOM-approved pilot production facility and the fabrication and qualification of PWBs in this facility. Subtasks associated with this task were a government-industry demonstration of the pilot line, delivery to MIRADCOM of five sets of PWBs fabricated in this pilot line for qualification purposes, and a 15-minute color/sound motion picture of the pilot-line operation. A third task in Phase II consisted of the design and documentation of a full-scale automated production line which was subsequently delivered to MIRADCOM.

TABLE 14. PHASE II TASKS

• Design, establishment, and qualification of pilot production line
• Fabrication of PWBs and qualification to MIL-Specs
• Design of automated production facility
• 16-mm motion-picture in color and sound depicting the PWB Processes
• Two-day industry/government debriefing session

2. TASK 1 – OPTIMIZATION AND VERIFICATION OF SELECTED PROCESSES

Hughes chose to optimize and verify the process for PWB fabrication using the ultra-thin copper-clad laminates. Where required, the basic process was further refined or modified to establish parameters to ensure uniformity and end product conformance to MIL-P-55110.

The results of the Phase I effort of this program revealed that all four of the material types tested passed the requirements of the MIL-specifications. The peelable type ultra-thin copper-clad material was chosen for this task because it and the related processes can be easily implemented into the majority of PWB fabrication systems utilizing the subtractive process.

The regular and modified ultra-thin copper-clad processes as outlined on the facing page were optimized for the production of PWBs that were subsequently tested for specification conformance. The regular process utilizes standard PWB fabrication techniques of drilling, hole plating, imaging, pattern plating of copper and tin/lead, etching, and fusing.

The modified process is used to produce "all-copper" PWBs and eliminates tin/lead plating and fusing from the sequence. The all-copper PWBs are subsequently coated with solder using the solder coater/air leveling equipment (SCL). In addition, PWBs were fabricated using the modified process plus a permanent solder mask as outlined in (C) of Figure 7, and solder coated using SCL.

Approximately 90 PWBs were fabricated over a two month period using each of the three described processes. Ten percent of these completed PWBs were subjected to the thermal stress testing of the PTHs as specified in MIL-P-55640 specifications. This test consisted of floating the PWBs on molten solder at 550°F for 10 seconds followed by microsectioning and examining the PTHs for copper cracks, copper separation or other anomolies. All of the PWBs passed the test requirements in that none of the PTH samples exhibited any evidence of copper cracks or separation of the plated copper from the hole wall, thereby indicating good PTH processing. It was also interesting to note that the PWBs processed through the SCL experienced no PTH failures and the resultant solder coverage afforded by the SCL was more than adequate.

At this time, the decision was made to concentrate on only the regular process for ultra-thin copper-clad material for subsequent evaluation in the pilot-production line environment. This process is the one that parallels more closely the production processes presently being used at Hughes-Fullerton.

Therefore, using the regular process, Hughes processed five test sets of two PWBs each in a sequential manner to simulate a low volume prototype PWB operation. To prove process capability, the last three successive sets (each set independently produced) were used to verify all the quality-conformance inspection tests of the MIL-P-55110 document.

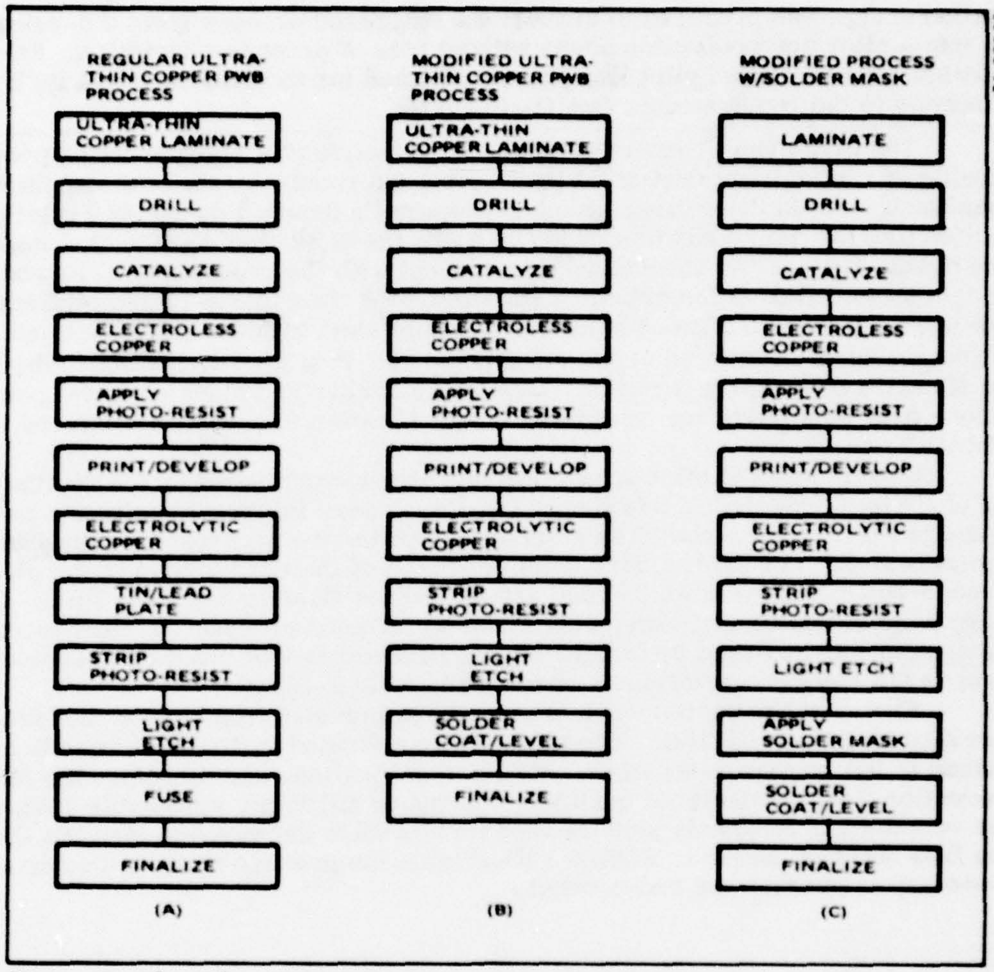


Figure 7. Ultra-Thin Copper Clad Processes. The modified processes in B and C produced "all-copper" type circuits.

3. TASKS 2, 3 AND 4 – DESIGN, ESTABLISHMENT AND QUALIFICATION OF A PILOT PRODUCTION LINE

A detailed design was prepared to convert the optimized process from a development phase into a pilot line production phase without loss of process effectivity. From this design, an unbalanced pilot line was established for the fabrication of PWBs for qualification to the requirements of MIL-P-55110.

The prior Task 1 effort obtained the objective of a manufacturing process capable of routinely producing PWBs meeting the requirements of the applicable specifications. In these tasks, Hughes prepared a detailed design of a pilot production line for the fabrication of PWBs using the ultra-thin copper-clad material. The design utilized the unbalanced line concept with the processing tanks and equipment in different locations. This eliminated the expense of establishing a new area. Most of the processing was accomplished with the equipment and facilities presently used in an engineering prototype shop for fabricating PWBs by the standard subtractive process. Layouts, sketches and other pictorial presentations fully describing the equipment in specification format was delivered to MIRADCOM.

Qualification of pilot production line was accomplished by the routine testing of PWBs fabricated in this line. The PWBs were fabricated using the peelable type ultra-thin copper-clad materials and following the processes outlined in Appendix B-3. The preliminary tests consisted of the examination of the plated-through-holes (PTHs) after thermal stress (solder float) tests of the PWB. Once these tests indicated that acceptable PTHs were being produced by the process, the system was qualified by fabricating ten production-type PWBs and subjecting them to the testing requirements specified in MIL-P-55110.

Five of these boards were chosen at random and subjected to the tests specified in MIL-P-55110B. The test results indicated that all five boards conformed to the requirements of the subject specification, and therefore the pilot production line was declared qualified to produce militarily acceptable PWBs. The remaining five boards plus the test results were delivered to MIRADCOM. The flow diagram shown in Figure 8 illustrates the process steps and equipment necessary to produce the end-product.

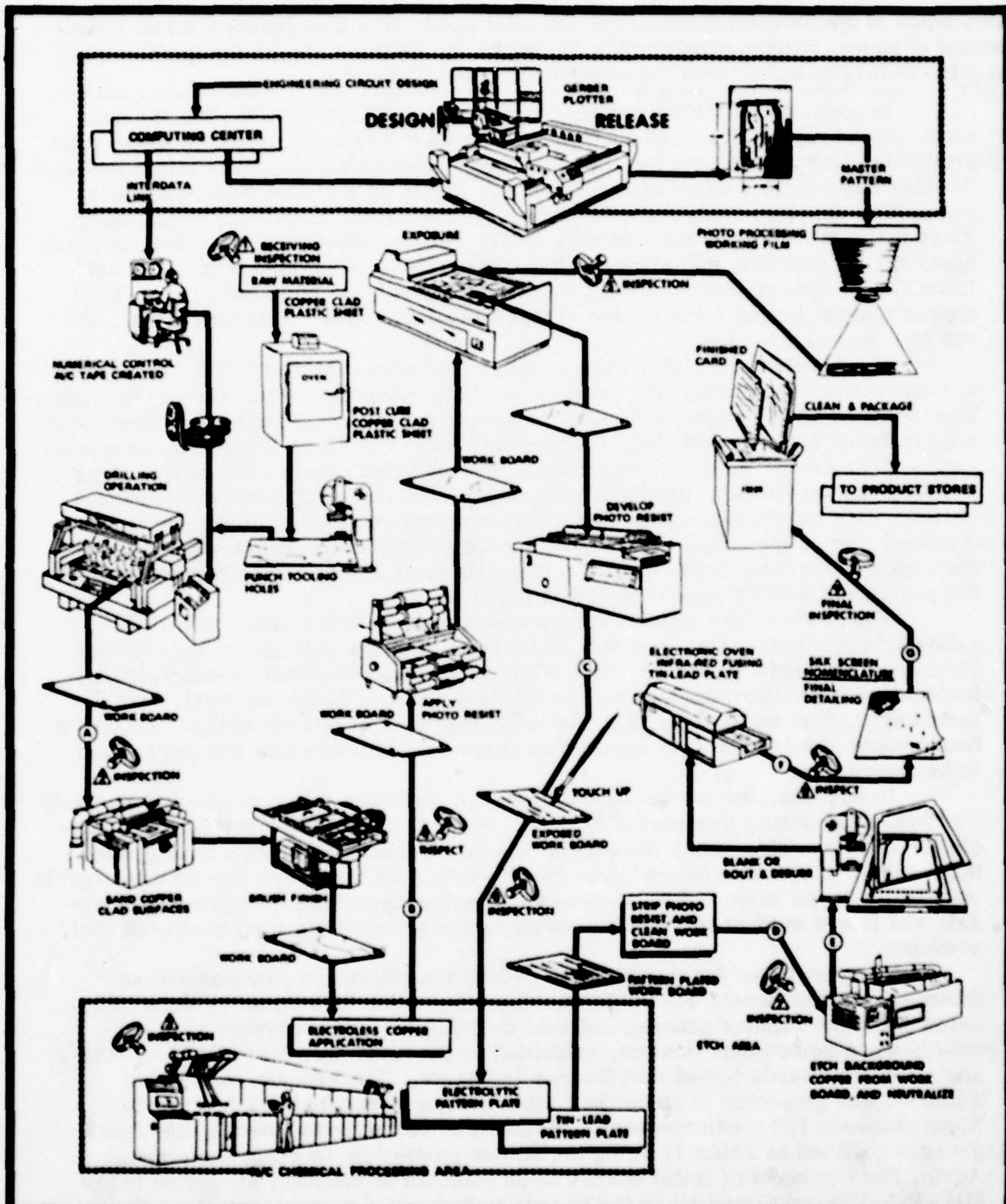


Figure 8. Typical Manufacturing Process Flow of a Printed Wiring Board. Precise controls are provided at all steps, from the generation of engineering data and plans through the application of materials and chemical solutions in fabrication, to the final cleaning and packaging of the finished card.

4. FABRICATION OF PWBs IN A PILOT PRODUCTION LINE

Two types of PWBs were produced in the pilot production line during a three-month period of time. Representative samples of the PWBs were chosen for qualification to MIL-P-55110, and all met the specification requirements.

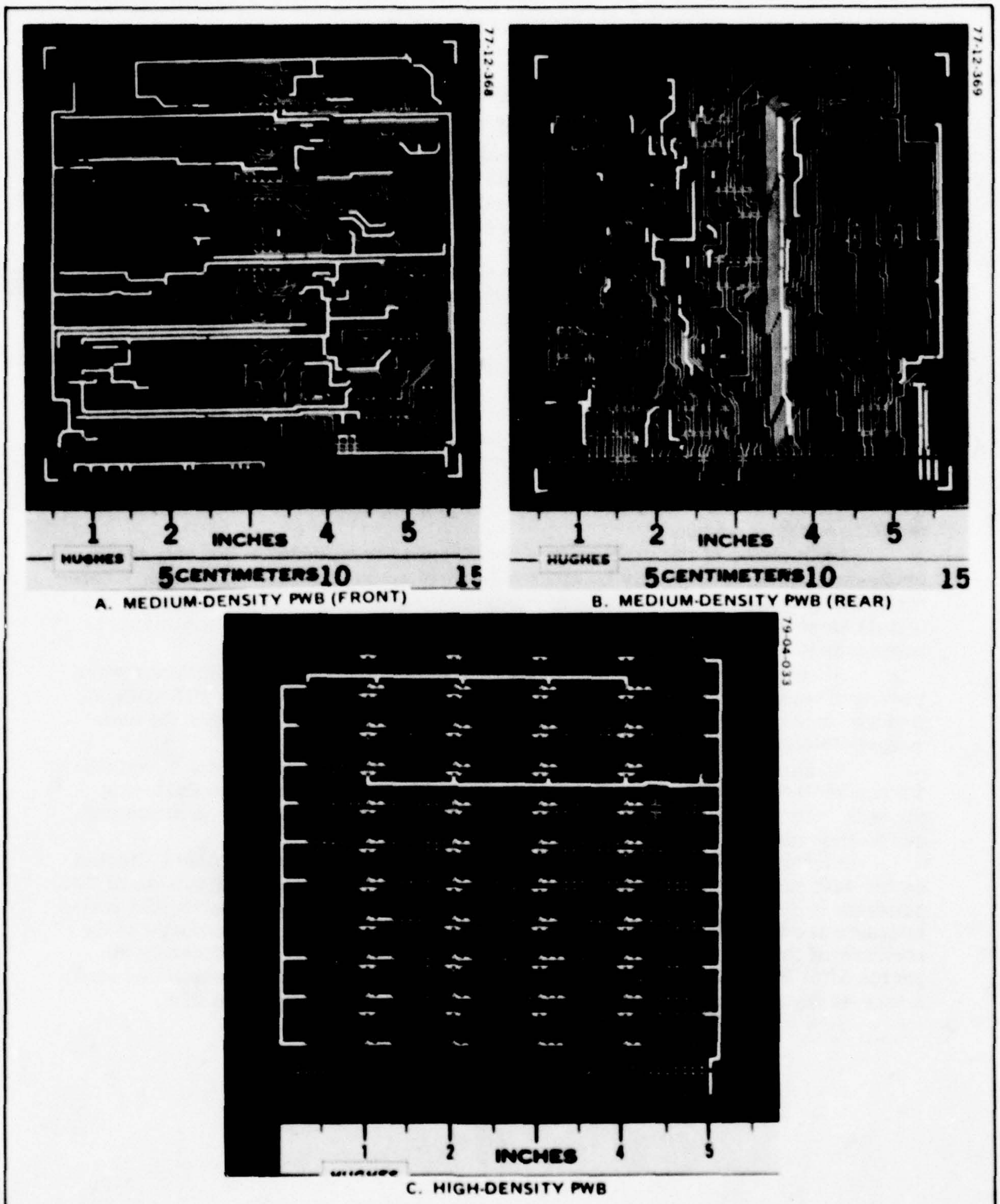
In order to verify the process and obtain additonal information for cost analysis and yield data, a production quantity of PWBs were produced in the pilot production line established and qualified in the previous task. This effort included the fabrication of medium- and high-density PWBs as pictured on the opposite page. The medium-density PWBs were fabricated using 0.062-inch thick epoxy glass material while the high-density PWBs were produced using 0.020-inch thick epoxy glass material, and include many #80 PTHs (0.0135-inch diameter) and 10 mil lines and spaces. Both of these board types were fabricated at a rate of approximately 10/day for a period of three months during which time a total of 600 PWBs were produced.

The regular ultra-thin PWB process sequence listed in Table 11 was used to fabricate approximately 450 medium- and high-density boards during this task. The modified PWB process utilizing the solder coater/air leveling equipment was used to fabricate approximately 150 medium density PWBs following the process sequence listed in Table 11. In addition, the modified process sequence, steps 1 through 8, was used to produce "all-copper" PWBs, which were subsequently coated with a permanent solder mask material conforming to IPC-SM-840. The terminal areas, bonding pads and PTHs were subsequently solder-coated using the solder coater/air leveler. Approximately forty PWBs were produced using the permanent solder mask during this program.

The process was monitored by randomly selecting 1 or 2 boards from each day's production run, and subjecting them to a thermal stress test (solder float for 10 seconds at 550°F). The PTHs were also examined metallurgically for evidence of failure anomolies. In addition, 2 or 3 PWBs per week were selected at random and subjected to the tests specified in MIL-P-55110. All of the boards submitted for testing during this three month production run were found to be acceptable.

In addition, the lot-to-lot variability of the ultra-thin copper-clad material was evaluated during this period of time. Several lots of the material were purchased over a twelve month period and used to fabricate the PWBs during this three month production effort. The results indicated that there was no discernable variability in the various lots of material received during this twelve month period, and it was evident that the laminators were maintaining good quality of their products.

The results of the three-month production effort are summarized as follows. Approximately 450 PWBs (both medium- and high-density) were fabricated using the regular process outlined in Table 11. Five percent of these boards were selected at random, subjected to the tests specified in MIL-P-55110, and all of the boards tested met the requirements. The process outlined in Table 11 was projected to result in a labor saving of approximately 2 percent. Approximately 150 medium-density PWBs were fabricated using the modified process outlined in Table 11 using the solder coater/air leveling equipment. Again, fiver percent of these boards were selected at random, subjected to the MIL-P-55110 tests, and all of the boards tested met the requirements. This modified process was projected to result in a labor saving of approximately 9 percent. All of the ultra-thin copper-clad material purchased over a twelve month period of time was found to be acceptable for use in fabricating PWBs conforming to the MIL-standards.



A. MEDIUM-DENSITY PWB (FRONT)

B. MEDIUM-DENSITY PWB (REAR)

C. HIGH-DENSITY PWB

Samples of Semi-Additive PWBs. Approximately 450 medium-density PWBs, and 150 high-density PWBs were fabricated in the pilot production line.

5. TASK 5 – AUTOMATED PRODUCTION LINE DESIGN

Hughes provided a specification for a production line capable of fabricating PWBs utilizing the ultra-thin copper-clad laminate material.

The automated production line design specification included a flow diagram of the fabrication processes; the specifications and physical data of equipment necessary to perform the various processing operations; and automated production systems wherever possible, such as the electroless and electrolytic plating lines.

Included in this design package were the latest specifications on a four-spindle numerically controlled (NC) drilling machine capable of drilling hundreds of 0.0135-inch diameter holes in laminate materials used for hi-density PWBs at Hughes-Fullerton. In addition, an overall layout of the automated sensitize and electroless copper plating line was provided including detail sketches of the process and rinse tanks used in this line. The same type of detail sketches were provided for the tanks in the copper and tin/lead plating line which is also automated and computer controlled. Pictures/sketches and physical specifications of other processing equipments were provided including the photoresist laminator, exposure machine, developer and stripper, a conveyorized etching machine, a conveyorized infrared solder fuser and cleaning machine, and finally an automated NC routing machine.

Each phase of the process was considered for automation but only those processes which could easily be automated were considered for this task. Therefore, the operations of applying and exposing the photoresist to the laminate materials were not automated whereas all of the other operations are automated to some extent through the use of conveyors, NC tapes, or computer.

All of the above mentioned drawings, data sheets and specifications were packaged together into a handbook type of document for delivery to MIRADCOM, and are included in Appendix B-4. Figure 9 on the facing page shows the automated plating line in operation at Hughes-Fullerton.

At the conclusion of Phase II, Hughes prepared and provided a 15-minute 16-mm motion picture (color and sound) depicting the complete manufacturing process. Each step of the process was documented with emphasis on areas unique to the semi-additive or ultra-thin copper process.

An industry/government debriefing session was held at Hughes-Fullerton on the 16th and 17th of November, 1978 to disseminate the data and results of this program to invited government and industry personnel. Approximately 125 invitations were sent to companies listed by MIRADCOM as well as members of the Institute of Printed Circuits and California Circuits Assn. Approximately 80 people attended the session. The debriefing and demonstration session included a tour of the Hughes-Fullerton facilities as well as a viewing of the film.

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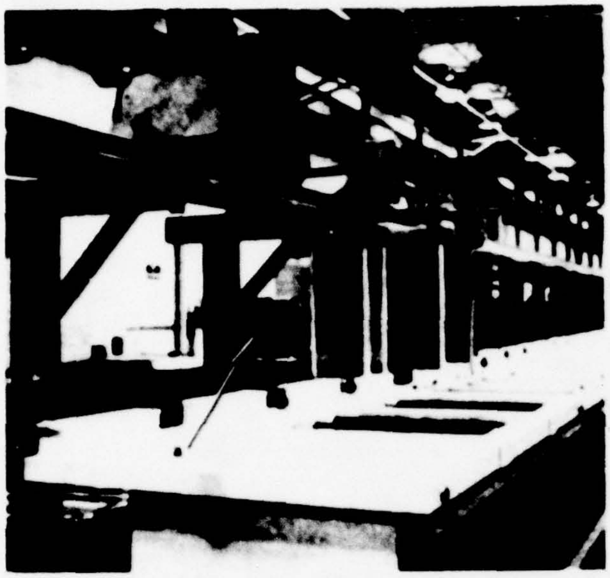
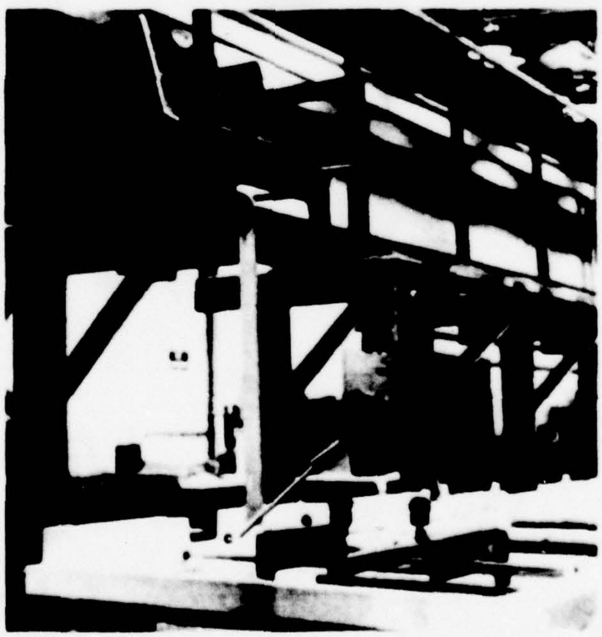


a) HOIST WITH BOARDS IN RETRACTED POSITION

b) BOARD IMMERSED



c) HOIST AND ACCOMPANYING I/O REAL-TIME PROCESS COMPUTER

Figure 9. Automated PWB Subtractive Processes Fabrication Line. The plating line hoist shown is computerized to control position and time of PWB immersion in various processing tanks.

SECTION 4
CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS REGARDING MATERIALS AND PROCESSES

PWBs fabricated using ultra-thin copper-clad, adhesive-coated, and sacrificial foil laminate materials qualified to the requirements of MIL-P-55110B. A pilot production line was established for the routine fabrication and qualification of PWBs using the ultra-thin copper-clad material.

Four types of epoxy-glass laminates (ultra-thin copper-clad with peelable or etchable carrier, sacrificial foil, and adhesively coated) meet the applicable requirements of MIL-P-13949 and MIL-P-55617. PWBs fabricated from each of these four material types qualified to the requirements of MIL-P-55110B. However, PWBs fabricated from adhesive-coated laminates must be treated with liquid FC/TMC solvent as an additional final step to remove the exposed adhesive layer between the circuitry pattern. This step is necessary because this adhesive layer contributes to the Insulation Resistance (IR) and humidity failures.

A pilot production line was designed, established and qualified for the production of PWBs using the ultra-thin copper-clad laminate material. PWBs were routinely sampled from the line and qualified to the requirements of MIL-P-55110B. The process was verified in this line and data was obtained relative to the reliability of the process based on the production of approximately 600 PWBs.

There was no evidence of "resin bleed through" problems on either type of ultra-thin copper-clad laminate material used in this program (peelable or etchable carrier). At least four lots of the peelable carrier type material were used to fabricate PWBs in the pilot production line. This observation of no resin-bleed-through was made on approximately 600 boards from these four material lots. In addition, drill burr problems were not experienced using the copper-clad laminates. This was accomplished by performing the drilling operation on PWBs sandwiched between an aluminum entry foil and an aluminum backup board in conjunction with the proper drill feeds and speeds.

A high-rate electroless copper system employing a 50Å type catalyst solution was successfully used to produce PWBs in a pilot production environment. A minimum thickness of 70 microinches of electroless copper was sufficient to eliminate the need for an electrolytic panel plating step. This system also provided good peel strength qualities of the deposited copper to both types of unclad laminates (the adhesive-coated and the sacrificial foil).

Using the modified processes described herein, all copper type PWBs were produced using either the ultra-thin copper-clad or semi-additive processes. These types of PWBs were successfully solder-coated using solder coater/air leveling equipment (SCL) thereby eliminating the conventional tin/lead plating and fusing operations. High-density circuits were also produced using the modified processes. They were coated with a permanent solder mask, and then the terminal areas and PTHs were solder coated using the SCL process. The use of these modified processes on the ultra-thin, all-copper PWBs resulted in a projected cost savings of 7 to 9 percent in labor. Additional savings attributed to extended etchant life and less chemical usage are indicated.

Material costs were obtained based on modest quantity lot sizes. These costs were compared with standard MIL-P-13949/4 laminates. The results showed that the ultra-thin copper-clad materials were 14 to 16 percent higher than the standard 1 oz/ft^2 material while the cost of adhesive-coated laminates was 9 percent higher. In contrast, the sacrificial foil laminates were priced 7 percent lower than the standard. In the future, new materials could reflect lower prices with increased demand, higher production, and additional competition. In

addition, some laminate types, due to little demand, are available in limited quantities from the laminators and require long lead times for delivery.

High-density PWBs can be produced using the materials and processes described herein. The ultra-thin copper-clad process can be implemented into a standard subtractive line with minimal costs for conversion.

The "seeded" type unclad laminates used for the fully additive processes were not acceptable for use in this program.

SUMMARY OF RESULTS AND CONCLUSIONS

- All four material types qualified to Military Specifications.
- PWBs fabricated from the four materials qualify to MIL-P-55110B.
- Adhesive-coated type PWBs must be treated in FC/TMC to pass IR tests after exposure to humidity.
- A pilot production line was designed, established and qualified for the production of PWBs using ultra-thin copper-clad laminates
- 600 PWBs were fabricated and qualified to military specifications during a 3-month period.
- No evidence of "resin bleed through" or drill burr problems using ultra-thin copper-clad material
- 50 Å catalyst/high-rate electroless copper system provides good peel strength qualities and eliminated need for copper panel plating.
- A modified process developed for production of "all-copper" type PWBs resulted in labor savings of 7 to 9%.
  - "All-copper" circuits were successfully solder coated using the solder coater/air leveler thereby eliminating the tin/lead plating and fusing operations.
  - PWBs with permanent solder mask were solder coated successfully using SCL.
  - All-copper PWBs can be produced using any of the four material types.
- Materials cost is higher for ultra-thin copper-clad and adhesive-coated laminates compared to standard 1 oz/ft^2 material. Sacrificial foil laminates are lower in cost.
- The ultra-thin copper-clad processes can be implemented into standard subtractive lines

2. RECOMMENDATIONS FOR FUTURE MM&T EFFORTS

It has been demonstrated that PWBs that conform to the requirements of MIL-P-55110B can be fabricated from ultra-thin copper-clad laminates. The material specifications should be updated to allow the use of 1/8 oz/ft^2 or 5-micron copper-clad laminates to allow production of such boards for the military.

The Department of Defense should update MIL-P-13949 to incorporate 1/8-oz/ft^2 or 5-micron copper-clad laminates. In addition, a new material specification should be established for the unclad laminates – adhesive-coated and sacrificial foil.

The processes advocated herein are also recommended for multilayer board (MLB) fabrication. After some evaluation, the applicable MLB requirements in MIL-STD-1495, MIL-P-55640, MIL-STD-275D and MIL-P-55110C be revised and upgraded accordingly. Both methodologies are recommended for additional development oriented towards the fabrication of low-cost microcircuitry (hybrids, etc.) utilizing resin-glass and ceramic dielectric substrates.

The present MM&T effort should be continued to evaluate the fully-additive process for military PWB fabrication. Although it requires extensive production facility restructuring, the fully-additive system is reported to be more cost effective than the semi-additive technology. An effort should be generated to determine whether additively produced PWBs will meet the end requirements of both MIL-P-55110 and MIL-P-55640.

Finally, it is recommended that a military specification be generated documenting the criteria for electroless copper deposition since electroless copper plating is an important factor in the construction of PWBs, particularly by the semi-additive and additive systems.

SUMMARY OF RECOMMENDATIONS

Recommendation	Advantage
• DoD update of MIL-P-13949 to include 5-micron copper-clad laminates and generate new specification for unclad laminates	• Allows use of this technology for military boards
• Use of these processes for MLBs	• Future refinement of thin MLB laminates will result in higher density MLBs
• Revision of MIL-STD-1495 and -275D, and MIL-P-55640 and -55110C.	• To allow military acceptance of PWBs produced using this technology
• Additional development of ultra-thin copper-clad and unclad MLB methodologies	• For low-cost hybrid microcircuitry
• Continue evaluation of the fully-additive process	• More cost effective than subtractive
• Create military specification for electroless copper deposition	• Improve the reliability of process and end product

APPENDIX A

APPENDIX A-1 – BIBLIOGRAPHY APPLICABLE TO SEMIADDITIVE PROCESS

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APPENDIX A-2 – APPLICABLE SPECIFICATIONS

1.	MIL-STD-202	Test Methods for Electronic and Electrical Component Parts
2.	MIL-STD-275	Printed Wiring for Electronic Equipment
3.	MIL-STD-429	Printed Wiring and Printed Circuit, Terms and Definitions
4.	MIL-STD-454	Standard General Requirements for Electronic Equipment
5.	MIL-STD-1495	Multilayer Printed Wiring Boards for Electronic Equipment
6.	MIL-P-13949	Plastic Sheet, Laminated, Metal-Clad (For Printed Wiring) General Specification for
7.	MIL-I-46058	Insulating Compound, Electrical (For Coating Printed Circuit Assemblies)

8.	MIL-P-55110	Printed Wiring Boards
9.	MIL-P-55617	Plastic Sheet, Thin Laminate, Metal-Clad (For Printed Wiring, Primarily for Multilayer)
10.	MIL-P-55640	Printed Wiring Boards, Multilayer (Plated-Through Hole)
11.	IPC-S-803	Solderability Test for Wave Soldered Printed Wiring Boards
12.	IPC-T-50A	Terms and Definitions
13.	IPC-AM-361	Specification for Rigid Substrates for Additive Processing of Printed Wiring Boards
14.	IPC-AM-372	Electroless Copper Film for Additive Printed Boards (Proposed)
15.	IPC-CF-155	Ultra-Thin Copper Foil (Proposed)
16.	IPC-SM-840	Qualification and Performance of Permanent Polymer Coating (Solder Mask) for Printed Boards
17.	IPC-TR-575	Additive Process Evaluation – Report on Phase I of the IPC Round Robin Testing Program on Additive Printed Wiring Boards
18.	IPC-TR-576	Additive Process Evaluation – Report on Phase II of the IPC Round Robin Testing Program on Rigid Additive Printed Boards

APPENDIX B

APPENDIX B-1

PROCEDURE FOR TESTING SEMI-ADDITIVE AND ULTRA-THIN COPPER CLAD PWBS

SCOPE

The scope of the procedure is to enumerate test methods which will be used to generate data on the performance of PWBs produced by the semi-additive or ultra-thin copper clad process. The data will be used to determine if PWBs, produced by one of the above processes, are suitable for military usage per specification MIL-P-55110.

BOARD IDENTIFICATION

Each board and specimen thereon shall be identified as to the source, type, process, and Hughes projected manufacturing date 1/. For example, source J's ultra-thin copper foil seeded laminate with an etchable carrier, processed using GSG's standard procedures, etched 23 September 1976 shall be identified as:

```
J    10    A    515
|    |     |     └── Manufacture Date (see Figure 1)
|    |     └── Applicable Process Procedure
|    └── Material Type (see Figure 2)
└── Material Source (see Figure 2)
```

PROCEDURE

The tests to be conducted are listed below and shall be performed in sequence (see Figure 3). Perform all cross-sectioning and destructive testing last. Do not discard any test specimens including those which have failed to meet the requirements.

A. Panel Evaluation

1. Visual Examination Requirements: MIL-P-55110B(2) 2/, Paragraph 4.9.1 Method of Test: A careful visual examination scanning both sides of each panel without magnification. Observe and record any obvious defects, damage, or poor workmanship. Check the following:

a. Agreement of panel and registration to master pattern.

b. Board edges - cracks, chips, etc.

c. Surface cracks - around holes and other buildup.

d. Board condition and workmanship - check for the presence of dirt, oil, corrosion, corrosive products, grease, fingerprints, foreign matter, flux residue, salts, etc.

e. Plating - check for cracks, lifting of coatings from resin surface and metal surface, slivers and whiskers, unwanted metal deposits, pinholes in metal deposits, presence of blisters, burnt deposits and other detrimental effects.

f. Plated-through-holes - examine all holes and record the locations of all voids present. Set aside panels having voids in holes for possible further investigation later.

Sample: 10" X 12" panels

Quantity: All panels

1/ Manufacturing date to be date fabrication of PWB starts.

2/ Including amendment or notice of referenced document.

HUGHES

1976 FISCAL CALENDAR

APPROVED HOLIDAYS

FIRST QUARTER

(1) JANUARY

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
1	29	30	31	1	2	3	4
2	5	6	7	8	9	10	11
3	12	13	14	15	16	17	18
4	19	20	21	22	23	24	25
5	26	27	28	29	30	31	1

(2) FEBRUARY

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
6	2	3	4	5	6	7	8
7	9	10	11	12	13	14	15
8	16	17	18	19	20	21	22
9	23	24	25	26	27	28	29

(3) MARCH

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
10	1	2	3	4	5	6	7
11	8	9	10	11	12	13	14
12	15	16	17	18	19	20	21
13	22	23	24	25	26	27	28

SECOND QUARTER

(4) APRIL

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
14	29	30	31	1	2	3	4
15	5	6	7	8	9	10	11
16	12	13	14	15	16	17	18
17	19	20	21	22	23	24	25
18	26	27	28	29	30	1	2

(5) MAY

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
19	3	4	5	6	7	8	9
20	10	11	12	13	14	15	16
21	17	18	19	20	21	22	23
22	24	25	26	27	28	29	30

(6) JUNE

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
23	31	1	2	3	4	5	6
24	7	8	9	10	11	12	13
25	14	15	16	17	18	19	20
26	21	22	23	24	25	26	27

THIRD QUARTER

(7) JULY

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
27	28	29	30	1	2	3	4
28	5	6	7	8	9	10	11
29	12	13	14	15	16	17	18
30	19	20	21	22	23	24	25
31	26	27	28	29	30	31	1

(8) AUGUST

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
32	2	3	4	5	6	7	8
33	9	10	11	12	13	14	15
34	16	17	18	19	20	21	22
35	23	24	25	26	27	28	29

(9) SEPTEMBER

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
36	30	31	1	2	3	4	5
37	6	7	8	9	10	11	12
38	13	14	15	16	17	18	19
39	20	21	22	23	24	25	26

FOURTH QUARTER

(10) OCTOBER

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
40	27	28	29	30	1	2	3
41	4	5	6	7	8	9	10
42	11	12	13	14	15	16	17
43	18	19	20	21	22	23	24
44	25	26	27	28	29	30	31

(11) NOVEMBER

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
45	1	2	3	4	5	6	7
46	8	9	10	11	12	13	14
47	15	16	17	18	19	20	21
48	22	23	24	25	26	27	28

(12) DECEMBER

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
49	29	30	1	2	3	4	5
50	6	7	8	9	10	11	12
51	13	14	15	16	17	18	19
52	20	21	22	23	24	25	26
53	27	28	29	30	31	1	2

APPROVED T. Nixon

Figure 1 – Fiscal Calendar (Sheet 1 of 2)

HUGHES

HUGHES AIRCRAFT COMPANY

1977 FISCAL CALENDAR

NO. [illegible]
DATE [illegible]
SUPERSEDES [illegible]
DATED [illegible]

$\boxed{}$ APPROVED HOLIDAYS*

FIRST QUARTER

(1) JANUARY

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
1	3	4	5	6	7	8	9
2	10	11	12	13	14	15	16
3	17	18	19	20	21	22	23
4	24	25	26	27	28	29	30

WORK HRS 160 DAYS 20 CUM DAYS 20

(2) FEBRUARY

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
5	31	1	2	3	4	5	6
6	7	8	9	10	11	12	13
7	14	15	16	17	18	19	20
8	21	22	23	24	25	26	27

WORK HRS 160 DAYS 20 CUM DAYS 40

(3) MARCH

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
9	28	1	2	3	4	5	6
10	7	8	9	10	11	12	13
11	14	15	16	17	18	19	20
12	21	22	23	24	25	26	27
13	28	29	30	31	1	2	3

WORK HRS 200 DAYS 25 CUM DAYS 65

SECOND QUARTER

(4) APRIL

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
14	4	5	6	7	8	9	10
15	11	12	13	14	15	16	17
16	18	19	20	21	22	23	24
17	25	26	27	28	29	30	1

WORK HRS 160 DAYS 20 CUM DAYS 85

(5) MAY

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
18	2	3	4	5	6	7	8
19	9	10	11	12	13	14	15
20	16	17	18	19	20	21	22
21	23	24	25	26	27	28	29

WORK HRS 160 DAYS 20 CUM DAYS 105

(6) JUNE

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
22	$\boxed{30}$	31	1	2	3	4	5
23	6	7	8	9	10	11	12
24	13	14	15	16	17	18	19
25	20	21	22	23	24	25	26
26	27	28	29	30	1	2	3

WORK HRS 192 DAYS 24 CUM DAYS 129

THIRD QUARTER

(7) JULY

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
27	$\boxed{4}$	5	6	7	8	9	10
28	11	12	13	14	15	16	17
29	18	19	20	21	22	23	24
30	25	26	27	28	29	30	31

WORK HRS 152 DAYS 19 CUM DAYS 148

(8) AUGUST

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
31	1	2	3	4	5	6	7
32	8	9	10	11	12	13	14
33	15	16	17	18	19	20	21
34	22	23	24	25	26	27	28

WORK HRS 160 DAYS 20 CUM DAYS 168

(9) SEPTEMBER

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
35	29	30	31	1	2	3	4
36	$\boxed{5}$	6	7	8	9	10	11
37	12	13	14	15	16	17	18
38	19	20	21	22	23	24	25
39	26	27	28	29	30	1	2

WORK HRS 192 DAYS 24 CUM DAYS 192

FOURTH QUARTER

(10) OCTOBER

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
40	3	4	5	6	7	8	9
41	10	11	12	13	14	15	16
42	17	18	19	20	21	22	23
43	24	25	26	27	28	29	30

WORK HRS 160 DAYS 20 CUM DAYS 212

(11) NOVEMBER

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
44	31	1	2	3	4	5	6
45	7	8	9	10	11	12	13
46	14	15	16	17	18	19	20
47	21	22	23	$\boxed{24}$	$\boxed{25}$	26	27

WORK HRS 144 DAYS 18 CUM DAYS 230

(12) DECEMBER

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
48	28	29	30	1	2	3	4
49	5	6	7	8	9	10	11
50	12	13	14	15	16	17	18
51	19	20	21	22	23	24	25
52	$\boxed{26}$	27	28	29	30	31	1

WORK HRS 152 DAYS [illegible] CUM DAYS [illegible]

* WHEN FLOATING HOLIDAYS FOR 1977 HAVE BEEN DETERMINED, A REVISION OF THIS CALENDAR WILL BE PUBLISHED REFLECTING RENUMBERED M-DAYS AND CORRECTED WORK DAYS. NOVEMBER 25 IS A PREDICTED FLOATING HOLIDAY

APPROVED: ____________
VICE PRESIDENT AND CONTROLLER

Figure 1 – Fiscal Calendar (Sheet 2 of 2)

FIGURE 2

MATERIALS ASSESSMENT AND SELECTION OF CANDIDATE MATERIAL

MATERIAL SOURCE BY CODE	AVAILABLE PWB MATERIALS									
	ADDITIVE LAMINATES						ULTRA-THIN COPPER FOIL LAMINATES			
	UNSEEDED			SEEDED			UNSEEDED		SEEDED	
	NO. 1 SWELL AND ETCH	NO. 2 ADHESIVE COATED	NO. 3 SACRIFICIAL FOIL	NO. 4 SWELL AND ETCH	NO. 5 ADHESIVE COATED	NO. 6 SACRIFICIAL FOIL	NO. 7 PEELABLE	NO. 8 ETCHABLE	NO. 9 PEELABLE	NO. 10 ETCHABLE
A	-	-		-	-	-			-	-
B	-	-	-	-	-	-	-	-	-	-
C	-		-	-		-	-	-	-	-
D	-	-	-	-	-	-	-	-	-	-
E	-	-	-	-	-	-	-	-	1/	
F	-	-	-	-	-	-	-		-	-
G	-	-		-		-		-		-
H	-		-	-		-	-	-		-
I	-	-		-	-	-			-	-
J	-	-	-	-	-	-	-	-	-	

NOTES:

1/ SPECIAL ORDER AT THIS TIME.
PROJECTED MATERIALS TO BE PROCURED FOR EVALUATION IN HEAVY OUTLINE.

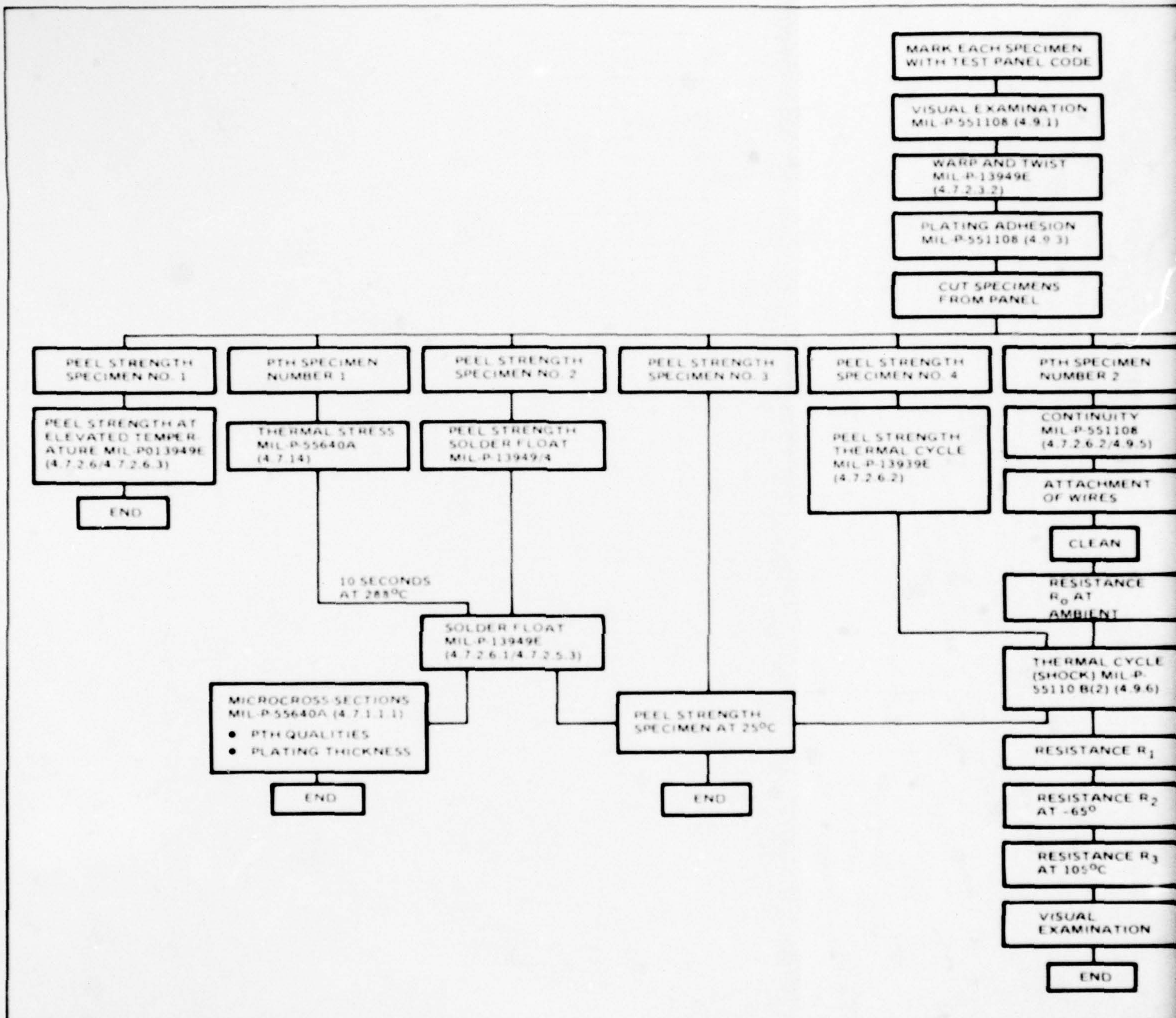


Figure 3. Te
additive or ult
preliminary sc

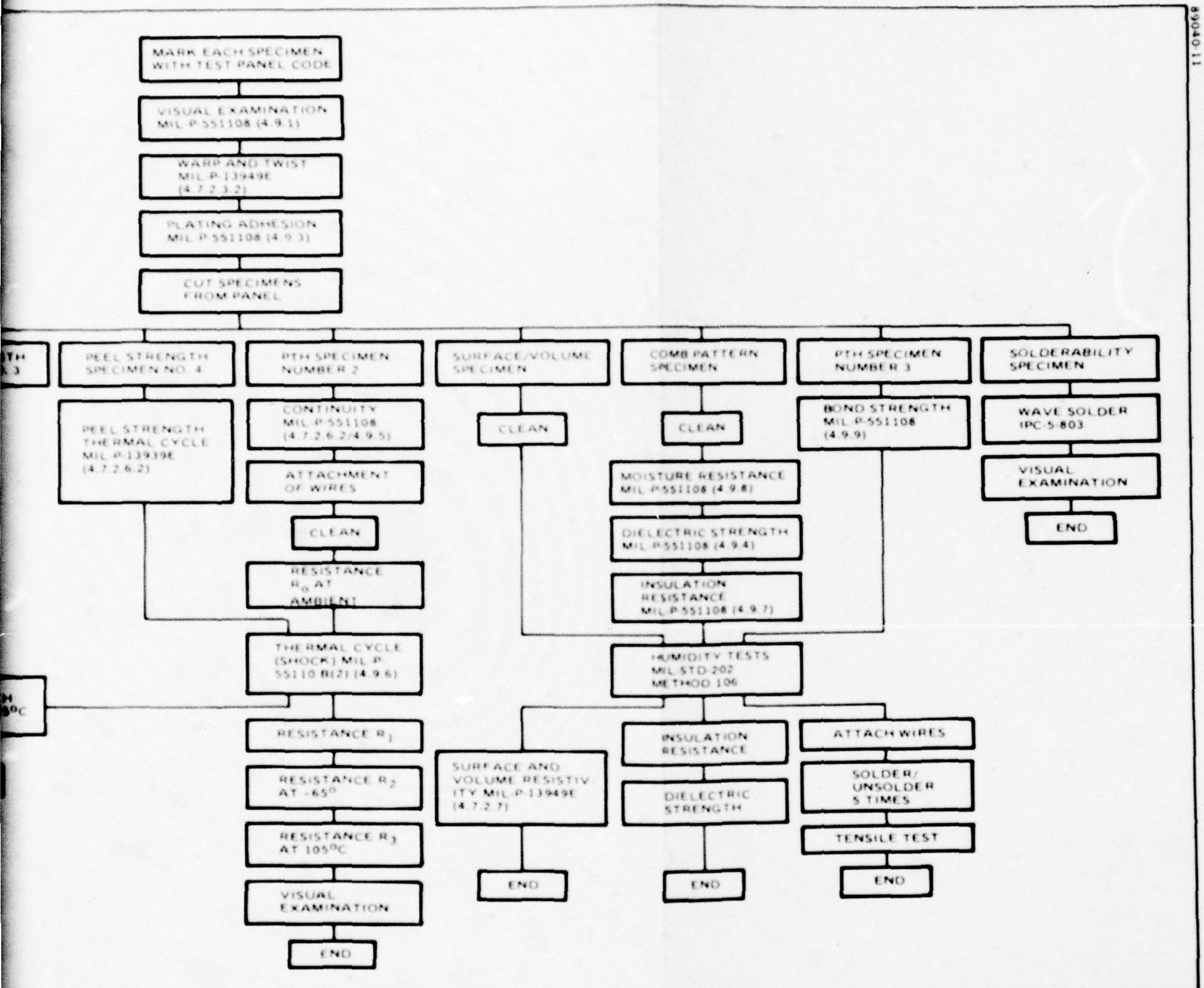


Figure 3. Test Plan Schematic. Projected test plan to evaluate test PWBs produced by the semi-additive or ultra-thin copper clad process. Those tests marked with an asterisk (*) are projected for preliminary screening evaluations.

2,

2. Warp and Twist

Requirements: MIL-P-13949E(1), Paragraph 3.4.1

Method of Test: MIL-P-13949E(1), Paragraph 4.7.2.3.2

Sample: 10" x 12" panels

Quantity: All panels

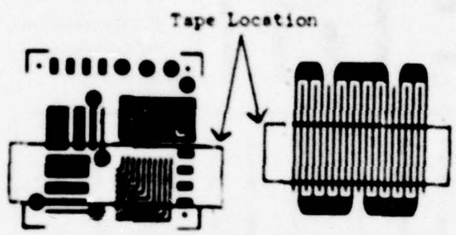
3. Plating Adhesion

Requirements: MIL-P-55110B(2), Paragraphs 3.5.2.1 and 3.6

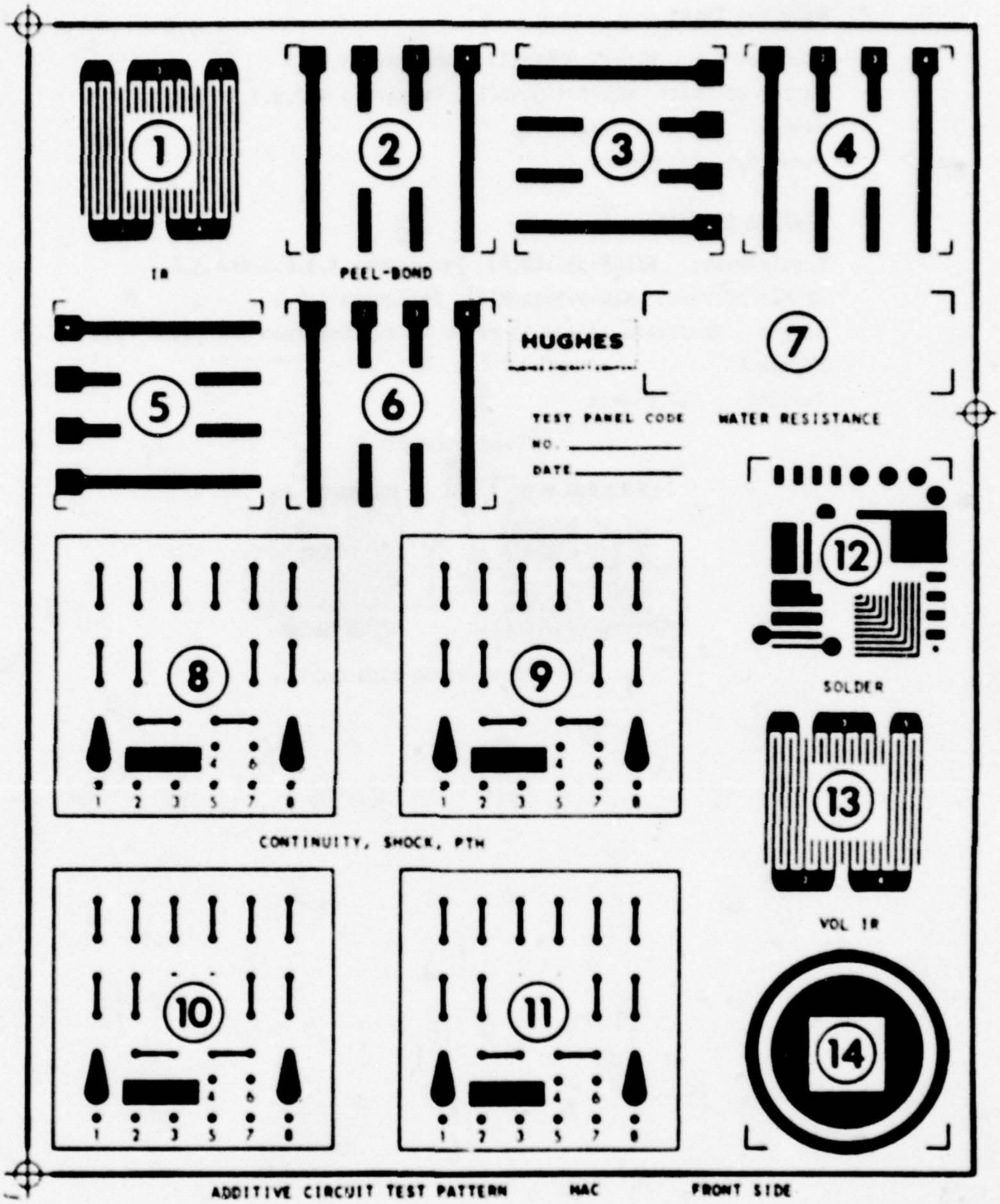
Method of Test: MIL-P-55110B(2), Paragraph 4.9.3

Sample: Specimens 12 and 13 prior to cutting from the panel (see Figure 4)

Quantity: All panels



Adhesion (Front Side Only)



SPECIMEN NUMBER REFERENCE PICTORIAL

FIGURE 4

B. Specimen Evaluation

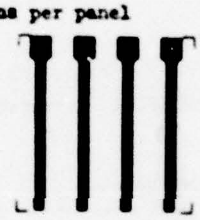
1. Cut specimens from panel to proceed with the following tests.

2. Peel Strength

   Requirements: MIL-P-55110B(2), Paragraph 3.13 and MIL-P-13949E(1) according to the required specification sheet.
   Method of Test: MIL-P-13949E(1), Paragraphs 4.7.2.5.3 and 4.7.2.6

   a. Test two strips per side minimum of Specimen 2 as received.
   b. Test two strips per side minimum of Specimen 3 after solder float per MIL-P-13949E(1), Paragraph 4.7.2.6.1.
      NOTE: If specimens are solder plated, wipe off excessive solder pick up immediately after solder float with a rubber squeegee.
   c. Test two strips per side minimum of Specimen 4 after temperature cycling per MIL-P-13949E(1), Paragraph 4.7.2.6.2.
   d. Test two strips per side minimum of Specimen 5 at elevated temperature per MIL-P-13949E(1), Paragraph 4.7.2.6.3.

   Samples: Peel-bond Specimens 2, 3, 4 and 5.
   Quantity: Four specimens per panel



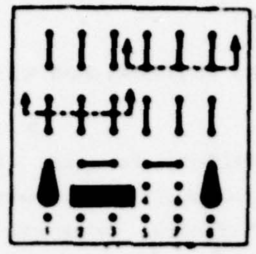
Peel-Bond

3. Plating Thickness

   Determine plating thickness of copper and of tin-lead deposits.
   Requirements: Copper - 1.4 mil minimum on conductors and 1.0 mil minimum in the holes; tin-lead - measure and record thickness.
   Method of Test: Thermal stress specimen per MIL-P-55640A(2), Paragraph 4.7.14 then micro cross-section per MIL-P-55640A(2), Paragraph 4.7.1.1.1. For tin-lead plated conductors measure the tin-lead thickness at the crown (crest) after fusing.

PTH
Cross-Section

Conductor
(Surface)
Cross-Section



Plating Thickness

Samples: Specimen 8

Quantity: One specimen per panel for surface and PTH plating thickness measurements. A minimum of three conductor and three PTH measurements required (see suggested cross-sectioning of specimen above). Place both cut sections in one metallographic mount and identify.

NOTE: Calculate the plating surface thickness to the plated-through-hole ration for copper plate.

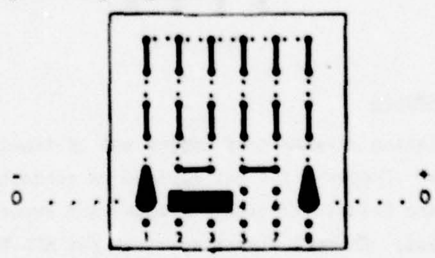
4. <u>Electrical Continuity</u>

Requirements: MIL-P-55110B(2), Paragraph 3.8

Method of Test: MIL-P-55110B(2), Paragraphs 4.7.1.2.1 and 4.9.5.

Sample: Specimen 9

Quantity: One specimen per panel



Wire Attachment

Electrical Continuity

5. <u>Moisture Resistance</u>

Requirements: MIL-P-55110B(2), Paragraph 3.11

Method of Test: MIL-P-5110B(2), Paragraph 4.9.8.

Prior to testing clean both sides of the specimen as follows:

Moisture Resistance

a. Brush with bristle brush under running D.I. water at 60-80°F.
b. Drain off water (drip-dry).
c. Brush while submerged in isopropyl alcohol removing all excess rosin.
d. Dip in fresh isopropyl alcohol; drain and dry in ambient air for 5 minutes (maximum).
e. Dry in oven at 225°F - 250°F for two hours.
f. Remove from oven and condition for 24 hours at 73°F prior to testing.

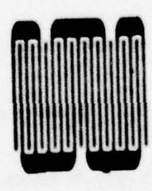
Sample: Specimen 1
Quantity: One specimen per panel
NOTE: Specimen 1 is also used for insulation resistance and dielectric withstanding voltage testing. Insulation resistance shall be tested per Paragraph B6. Dielectric withstanding voltage shall be measured within 10 minutes after removal from the humidity chamber.

6. <u>Insulation Resistance and Dielectric Withstand Voltage</u>

Requirement: MIL-P-55110B(2), Paragraphs 3.7 and 3.10
Method of Test: MIL-P-55110B(2), Paragraphs 4.7.1.2.3 and 4.9.4 except as follows:

a. 100 VDC polarizing voltage shall be applied continuously during humidity exposure.
b. Insulation resistance shall be determined prior to the test (ambient) and during the 5th and 10th cycle while within the humidity chamber.

Sample: Specimen 1, both sides to be tested
Quantity: One specimen per panel



Insulation Resistance and
Dielectric Withstanding Voltage

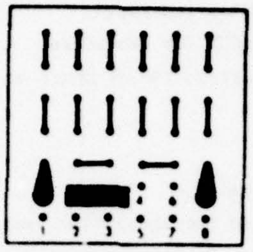
7. **Bond Strength (PTH)**

Requirements: MIL-P-55110B(2), Paragraph 3.12

Method of Test: After exposure to humidity per MIL-STD-202, Method 106 test per MIL-P-55110B(2), Paragraph 4.9.9.

Sample: Specimen 10

Quantity: Test hole numbers 1, 2, 3 and 8 of Specimen 10.



Bond Strength

8. Surface and Volume Resistivity

Requirements: MIL-P-13949E(1), Paragraph 3.8

Surface and Volume Resistivity

Method of Test: MIL-P-13949E(1), Paragraph 4.7.2.7 after humidity exposure per FED-STD-406 Method 40ll (see IPC test method 2.5.17 for reference). Prior to humidity exposure clean the specimens as follows:

a. Brush with bristle brush under running D.I. water at 60-80°F.
b. Drain off water (drip-dry).
c. Brush while submerged in isopropyl alcohol removing all excess rosin.
d. Dip in fresh isopropyl alcohol; drain and dry in ambient air for 5 minutes (maximum).
e. Dry in oven at 225°F - 250°F for 2 hours.
f. Remove from oven and condition for 24 hours at 73°F prior to humidity conditioning.

Sample: Specimen 14

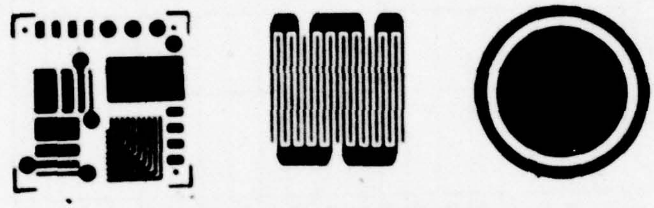
Quantity: One specimen per panel

9. Solderability

Requirements: Test for solderability and blistering. If blistering occurs specify location; for example, at the substrate or between solder and the plated finish.

Method of Test: Test per IPC-S-803 all testing and judgements shall be performed by one operator and as far as practicable in the shortest possible time span. Prior to fluxing and soldering, clean the test specimens as follows:

a. Brush with a nylon brush, while submerged in isopropyl alcohol, removing all residual flux resin.
b. Dip in fresh isopropyl alcohol drain and dry in ambient air for 5 minutes (maximum).
c. Dry in oven at 225°F - 250°F for two hours.
d. Remove from oven and condition for 24 hours prior to testing at 73°F.



Solderability (Front Side)

Sample: Specimens 12, 13 and 14

Quantity: One section of specimens per panel

10. Water Absorption (Optional)2/

Requirements: MIL-P-13949E(1), Paragraph 3.9

Method of Test: MIL-P-13949E(1), Paragraph 4.7.2.8

Sample: Specimen 7

Quantity: One specimen per panel

2/ Test to be performed on selected candidate materials only.

APPENDIX B-2 – TEST DATA SHEETS

PAGE NO.____ OF ________

DATE: ______________

TESTER'S NAME: ____________

TEST DATA SHEET

	EXAM PARAGRAPH NUMBER										
	B9 SOLDERABILITY		B4 CONTINUITY						B7 BOND STRENGTH		
	SPECIMENS 12, 13, & 14		SPECIMEN NO. 9						SPECIMEN NO. 10		
SPECIMEN CODE NUMBER	CONDITION	COMMENT*	OBS. R, Ω		TEMP °C	COR. R, Ω		% CHANGE	HOLE NO.	LBS.	OBSERVATION COMMENTS**
	NON-WETTING		R_1			RC_1			1		
	DE-WETTING		R_2			RC_2			2		
	PIN HOLES		R_3			RC_3			3		
	GENERAL APPEAR.		R_4			RC_4			8		
	NON-WETTING		R_1			RC_1			1		
	DE-WETTING		R_2			RC_2			2		
	PIN HOLES		R_3			RC_3			3		
	GENERAL APPEAR.		R_4			RC_4			8		
	NON-WETTING		R_1			RC_1			1		
	DE-WETTING		R_2			RC_2			2		
	PIN HOLES		R_3			RC_3			3		
	GENERAL APPEAR.		R_4			RC_4			8		
	NON-WETTING		R_1			RC_1			1		
	DE-WETTING		R_2			RC_2			2		
	PIN HOLES		R_3			RC_3			3		
	GENERAL APPEAR.		R_4			RC_4			8		
	NON-WETTING		R_1			RC_1			1		
	DE-WETTING		R_2			RC_2			2		
	PIN HOLES		R_3			RC_3			3		
	GENERAL APPEAR.		R_4			RC_4			8		

* COMMENT TO BE EXPRESSED IN PERCENTAGE WHERE APPLICABLE OR ONE WORD OBSERVATION: EXCEL., GOOD, POOR.

** BOND STRENGTH CODE:

(1) WIRE NOT BROKEN, NO PTH DAMAGE.
(2) WIRE NOT BROKEN, TOP PAD AND PTH WITH WIRE, BOTTOM PAD NOT DAMAGED.
(3) WIRE NOT BROKEN, TOP PAD WITH WIRE, TOP AND BOTTOM PADS NOT DAMAGED.
(4) WIRE BROKEN, NO VISIBLE DAMAGE TO SOLDER JOINT OR PTH.

PAGE NO.____OF__________

DATE:__________

TESTER'S NAME:__________

TEST DATA SHEET

		EXAM PARAGRAPH NUMBER								
		B6 DIELECTRIC STRENGTH VOLTAGE			A2 WARP AND TWIST				A3 PLATING ADHESION	
					ENTIRE PANEL					
		SPECIMEN NO. 1			WARP		TWIST		OBSERVATION COMMENT*	
SPECIMEN CODE NUMBER		PASS	REJ	COMMENT	MILS	%	MILS	%	SPEC. NO. 12	SPEC. NO. 13
	FRONT									
	REVERSE									
	FRONT									
	REVERSE									
	FRONT									
	REVERSE									
	FRONT									
	REVERSE									
	FRONT									
	REVERSE									
	FRONT									
	REVERSE									
	FRONT									
	REVERSE									
	FRONT									
	REVERSE									
	FRONT									
	REVERSE									
	FRONT									
	REVERSE									

* SLIVERS, SN/PB SEP(ARATION), CU/CU SEP(ARATION), OVERHANG; ACC(EPTABLE).

PAGE NO.____OF____________

DATE:____________________

TESTER'S NAME:____________

TEST DATA SHEET

	EXAM PARAGRAPH NUMBER							
	B6 INSULATION RESISTANCE (OHMS)			B8 RESISTIVITY R (MEGΩ), r = MEGΩ-CM; A = CM^2; t = CM			B10 WATER ABSORPTION	
	SPECIMEN NO. 1			UNIT	SPECIMEN NO. 14		UNIT	SPECIMEN NO. 7
SPECIMEN CODE NUMBER	TEST AT	F	R		VOLUME	SURFACE		
	AMBIENT			R			W_2	g
	5TH-			A			W_1	g
	10TH-			t			W_2-W_1	g
				r			%	g
	AMBIENT			R			W_2	g
	5TH-			A			W_1	g
	10TH-			t			W_2-W_1	g
				r			%	g
	AMBIENT			R			W_2	g
	5TH-			A			W_1	g
	10TH-			t			W_2-W_1	g
				r			%	g
	AMBIENT			R			W_2	g
	5TH-			A			W_1	g
	10TH-			t			W_2-W_1	g
				r			%	g
	AMBIENT			R			W_2	g
	5TH-			A			W_1	g
	10TH-			t			W_2-W_1	g
				r				g
	AMBIENT			R			W_2	g
	5TH-			A			W_1	g
	10TH-			t			W_2-W_1	g
				r			%	g

PAGE NO._____OF ___________

DATE: ____________________

TESTER'S NAME: _____________

TEST DATA SHEET

SPECIMEN CODE NUMBER	EXAM PARAGRAPH NUMBER, 83							
	PLATING THICKNESS/SURFACE TO HOLE RATIO (SPECIMEN NO. 8)							
			THICKNESS, MILS				COMMENTS	RATIO; ** SURFACE/HOLE
			1	2	3	AV		
	CONDUCTOR (FRONT)	SOLDER*		—	—	—		
		COPPER						
	CONDUCTOR (REVERSE)	SOLDER*		—	—	—		
		COPPER						
	PTH (WALL)	SOLDER*		—	—	—		
		COPPER						
	CONDUCTOR (FRONT)	SOLDER*		—	—	—		
		COPPER						
	CONDUCTOR (REVERSE)	SOLDER*		—	—	—		
		COPPER						
	PTH (WALL)	SOLDER*		—	—	—		
		COPPER						
	CONDUCTOR (FRONT)	SOLDER*		—	—	—		
		COPPER						
	CONDUCTOR (REVERSE)	SOLDER*		—	—	—		
		COPPER						
	PTH (WALL)	SOLDER*		—	—	—		
		COPPER						
	CONDUCTOR (FRONT)	SOLDER*		—	—	—		
		COPPER						
	CONDUCTOR (REVERSE)	SOLDER*		—	—	—		
		COPPER						
	PTH (WALL)	SOLDER*		—	—	—		
		COPPER						

* AT CREST.

** RATIO OF PLATING SHALL BE COMPUTED FROM THE AVERAGE OF DATA TAKEN FROM THIS TABLE. EXAMPLE: THE RATIO IS COMPUTED BY DIVIDING THE AVERAGE OF SIX TOTAL LINE MEASUREMENTS BY THE AVERAGE OF THREE TOTAL HOLE MEASUREMENTS.

PAGE NO. ____ OF ____

DATE ____________________

TESTER'S NAME ____________

TEST DATA SHEET

SPECIMEN CODE NUMBER	EXAM PARAGRAPH NUMBER 28. PEEL STRENGTH							
	LINE MEASUREMENTS (MILS)			PEEL STRENGTH (LBS)			CHECK AS APPLICABLE	
	NO.	WIDTH	THICKNESS	(MIN)	(NOM)	(MAX)	TYPE OF TEST	SPECIMEN NO.
	1						☐ AS RECEIVED	☐ 2F ☐ 2R
	2						☐ AFTER SOLDER FLOAT	☐ 3F ☐ 3R
	3						☐ AFTER TEMP CYCLE	☐ 4F ☐ 4R
	4						☐ AFTER ELEVATED TEMP	☐ 5F ☐ 5R
	1						☐ AS RECEIVED	☐ 2F ☐ 2R
	2						☐ AFTER SOLDER FLOAT	☐ 3F ☐ 3R
	3						☐ AFTER TEMP CYCLE	☐ 4F ☐ 4R
	4						☐ AFTER ELEVATED TEMP	☐ 5F ☐ 5R
	1						☐ AS RECEIVED	☐ 2F ☐ 2R
	2						☐ AFTER SOLDER FLOAT	☐ 3F ☐ 3R
	3						☐ AFTER TEMP CYCLE	☐ 4F ☐ 4R
	4						☐ AFTER ELEVATED TEMP	☐ 5F ☐ 5R
	1						☐ AS RECEIVED	☐ 2F ☐ 2R
	2						☐ AFTER SOLDER FLOAT	☐ 3F ☐ 3R
	3						☐ AFTER TEMP CYCLE	☐ 4F ☐ 4R
	4						☐ AFTER ELEVATED TEMP	☐ 5F ☐ 5R
	1						☐ AS RECEIVED	☐ 2F ☐ 2R
	2						☐ AFTER SOLDER FLOAT	☐ 3F ☐ 3R
	3						☐ AFTER TEMP CYCLE	☐ 4F ☐ 4R
	4						☐ AFTER ELEVATED TEMP	☐ 5F ☐ 5R
	1						☐ AS RECEIVED	☐ 2F ☐ 2R
	2						☐ AFTER SOLDER FLOAT	☐ 3F ☐ 3R
	3						☐ AFTER TEMP CYCLE	☐ 4F ☐ 4R
	4						☐ AFTER ELEVATED TEMP	☐ 5F ☐ 5R

PAGE NO. ____ OF ____

DATE: ____

TESTER'S NAME: ____

VISUAL EXAMINATION (PANEL) DATA SHEET*

SPECIMEN CODE NUMBER	EXAM PARAGRAPH NUMBER, A1					
	a	b	c	d	e	f
	•PATTERN AGREEMENT •REGISTRATION	•BOARD EDGES •CHIPS •CRACKS •DAMAGE	CRACKS •SURFACE •AROUND HOLES	CONTAMINATION •DIRT •OIL •CORROSION •FLUX •OTHER	•PLATING QUALITIES •CRACKS •SLIVERS •BLISTERS •POOR COVERAGE •OTHER	•PTH VOIDS •NUMBER •LOCATION •TOP •CENTER

* RECORD, YES, NO, OR COMMENT IN EACH BLANK. IF COMMENTS ARE EXTENSIVE, CONTINUE ON BACK OF PAGE.

PAGE NO. 2 OF 3

DATE 2-24-77

TESTER'S NAME D. QUIRK

TEST DATA SHEET

	EXAM PARAGRAPH NUMBER 82, PEEL STRENGTH								
	LINE MEASUREMENTS (MILS)			PEEL STRENGTH			CHECK AS APPLICABLE		
SPECIMEN CODE NUMBER	NO.	WIDTH	THICKNESS	MIN, LBS	MAX, LBS	LBS/IN*	TYPE OF TEST	SPECIMEN NO.	
FRONT I3B623F-2	1	.125	1.3	1.74	1.98	13.92	☐ AS RECEIVED	☐ 2F	☐ 2R
	2	.125		1.76	1.99	14.08	☒ AFTER SOLDER FLOAT	☒ 3F	☐ 3R
	3	.125		1.75	2.00	14.00	☐ AFTER TEMP CYCLE	☐ 4F	☐ 4R
	AV	—	—			14.0	☐ AFTER ELEVATED TEMP	☐ 5F	☐ 5R
REVERSE I3B623F-2	1	.125	1.4	2.35	2.50	18.80	☐ AS RECEIVED	☐ 2F	☐ 2R
	2	.125		2.0	2.24	16.00	☒ AFTER SOLDER FLOAT	☐ 3F	☒ 3R
	3	.125		2.19	2.44	17.52	☐ AFTER TEMP CYCLE	☐ 4F	☐ 4R
	AV	—	—			17.4	☐ AFTER ELEVATED TEMP	☐ 5F	☐ 5R
FRONT H2G613F-1	1	.125		2.20	2.45	17.60	☐ AS RECEIVED	☐ 2F	☐ 2R
	2	.125		2.22	2.67	17.76	☒ AFTER SOLDER FLOAT	☒ 3F	☐ 3R
	3	.125		2.23	2.42	17.84	☐ AFTER TEMP CYCLE	☐ 4F	☐ 4R
	AV	—	—			17.7	☐ AFTER ELEVATED TEMP	☐ 5F	☐ 5R
REVERSE H2G613F-1	1	.125		2.20	2.47	17.60	☐ AS RECEIVED	☐ 2F	☐ 2R
	2	.125		2.02	2.22	16.16	☒ AFTER SOLDER FLOAT	☐ 3F	☒ 3R
	3	.125		2.13	2.40	17.04	☐ AFTER TEMP CYCLE	☐ 4F	☐ 4R
	AV	—	—			16.9	☐ AFTER ELEVATED TEMP	☐ 5F	☐ 5R
FRONT H2G613F-2	1	.125	1.3	2.34	2.55	18.72	☐ AS RECEIVED	☐ 2F	☐ 2R
	2	.125		2.48	2.60	19.84	☒ AFTER SOLDER FLOAT	☒ 3F	☐ 3R
	3	.125		2.43	2.51	19.44	☐ AFTER TEMP CYCLE	☐ 4F	☐ 4R
	AV	—	—			19.3	☐ AFTER ELEVATED TEMP	☐ 5F	☐ 5R
REVERSE H2G613F-2	1	.125	1.9	2.72	2.89	21.76	☐ AS RECEIVED	☐ 2F	☐ 2R
	2	.125		2.86	3.18	22.88	☒ AFTER SOLDER FLOAT	☐ 3F	☒ 3R
	3	.125		2.77	2.93	22.16	☐ AFTER TEMP CYCLE	☐ 4F	☐ 4R
	AV	—	—			22.3	☐ AFTER ELEVATED TEMP	☐ 5F	☐ 5R

* LBS/IN OF CONDUCTOR WIDTH BASED ON MINIMUM LOAD.

A TYPICAL DATA SHEET WITH TEST RESULTS

APPENDIX B-3 – FABRICATION PROCEDURES, FINAL

TABLE 1: FINAL PROCESS A FOR THIN COPPER CLAD MATERIAL WITH PEELABLE CARRIER

STEP	PROCESS	TIME	SOLUTION	TEMP	REMARKS
1	Identify Material				
2	Tape Drill				Use Aluminum Clad Backup Board, Aluminum Entry Foil, and New Drills.
3	Peel Carrier				Avoid Hand and Finger Contact
4	Proceed to Table 5, Step 8				

TABLE 2: FINAL PROCESS E FOR THIN COPPER CLAD MATERIAL WITH ETCHABLE CARRIER

STEP	PROCESS	TIME	SOLUTION	TEMP	REMARKS
1	Identify Material				
2	Tape Drill				Use Aluminum Clad Backup Board, Aluminum Entry Foil, and New Drills
3	Carrier Removal	As Req'd	40 ± 10% HCl	R.T.	
4	Rinse	1-2 Mins.	Tap Water	R.T.	
5	Proceed to Table 5, Step 8				

TABLE 3: FINAL PROCESS B FOR UNCLAD MATERIAL WITH SACRIFICAL FOIL (FLADD 2)

STEP	PROCESS	TIME	SOLUTION	TEMP	REMARKS
1	Identify Material				
2	Tape Drill				Use Aluminum Clad Backup Board, Aluminum Entry Foil, and New Drills
3	Carrier Removal	As Req'd.	40 ± 10% HCl	R.T.	
4	Rinse	1-2 Mins.	Tap Water	R.T.	
5	Conditioner	10 ± 1 Mins.	Metex M-80 Conditioner	160±10°F	
6	Rinse	1-2 Mins.	Tap Water	R.T.	
7	Proceed to Table 5, Step 8				

TABLE 4: FINAL PROCESS G FOR UNCLAD MATERIAL WITH ADHESIVE COATING

STEP	PROCESS	TIME	SOLUTION	TEMP	REMARKS
1	Identify Material				
2	Tape Drill				Use Aluminum Clad Backup Board, Aluminum Entry Foil, and New Drills.
3	Adhesion Promotion	10 ± 1 Mins.	Chromic/Sulfuric Acid	110±10°F	
4	Dragout Rinse	1-2 Mins.	Sodium Meta-Bisulfite #1	R.T.	
5	Neutralize	1-2 Mins.	Sodium Meta-Bisulfite #2	R.T.	
6	Rinse	2-3 Mins.	Tap Water	R.T.	
7	Proceed to Table 5, Step 8				

TABLE 5: FABRICATION OF PRINTED WIRING BOARDS WITH PLATED-THRU-HOLES
STEPS COMMON TO ALL PROCESSES

STEP	PROCESS	TIME	SOLUTION	TEMP	REMARKS
1-7	Boards Processed Per Table 1,2,3, or 4				
8	Condition	5-10 Mins.	Shipley 1160	R.T.	
9	Rinse	1-2 Mins.	Tap Water	R.T.	
10	HCl Dip	1-2 Mins.	2% HCl	R.T.	
11	Activate	10 Mins.	Mac Dermid 9070M Catalyst	R.T.	
12	Immersion Rinse	1-2 Mins.	Tap Water	R.T.	
13	Spray Rinse	60-90 Sec.	D.I. Water	R.T.	
14	Accelerate	3-6 Mins.	Mac Dermid 9071	R.T.	
15	Immersion Rinse	60-90 Sec.	Tap Water	R.T.	
16	Spray Rinse	60-90 Sec.	D.I. Water	R.T.	
17	Electroless Copper	15-25 Mins.	Mac Dermid 9055	120±5°F	
18	Immersion Rinse	1-2 Mins.	Tap Water	R.T.	
19	Spray Rinse	1-2 Mins.	D.I. Water	R.T.	

TABLE 5: CONTINUED

STEP	PROCESS	TIME	SOLUTION	TEMP	REMARKS
20	Air Blow Dry	As Req'd.			Use oil free clean dry air.
21	Oven Dry	30-60 Mins.		300±20°F	For Non-Copper Clad Boards only.
22	Clean for Photoresist Application, Rinse, Dry				
23	Apply, Expose, Develop, and Touch Up Resist		Du Pont Riston 1165 Dry Film Resist.		Use Positive Film
24	Acid Clean	2-5 Mins.	Mac Dermid Metex L-5B	R.T.	
25	Immersion Rinse	1-2 Mins.	Tap Water		
26	Spray Rinse	1-2 Mins.	D.I. Water		
27	A. P. Clean	15-30 Sec.	15% Ammonium Persulfate	R.T.	
28	Rinse	1-2 Mins.	Tap Water	R.T.	

TABLE 5: CONTINUED

STEP	PROCESS	TIME	SOLUTION	TEMP	REMARKS
29	Spray Rinse	1-2 Mins.	D.I. Water	R.T.	
30	Sulfuric Acid Dip	1-2 Mins.	2% Sulfuric Acid	R.T.	
31	Immersion Rinse	1-2 Mins.	Tap Water		
32	Spray Rinse	1-2 Mins.	D.I. Water		
33	Acid Copper Plate	See Remarks	Lea-Ronal Copper Sulfate	R.T.	10-40ASF 1.0MIL Copper in Hole
34	Rinse	1-2 Mins.	Tap Water	R.T.	
35	Rerack				
36	Acid Clean	2-5 Mins.	Metex L-5B	R.T.	
37	Immersion Rinse	1-2 Mins.	Tap Water	R.T.	
38	Spray Rinse	1-2 Mins.	D.I. Water	R.T.	
39	Etchant Clean	1-2 Mins.	15% Ammonium Persulfate	R.T.	
40	Rinse	1-2 Mins.	Tap Water	R.T.	

TABLE 5: CONTINUED

STEP	PROCESS	TIME	SOLUTION	TEMP	REMARKS
41	Spray Rinse	1-2 Mins.	D.I. Water	R.T.	
42	Fluoboric Acid	1-3 Mins.	10% HBF_4	R.T.	
43	Tin-Lead Plate	See Remarks	Fluoborate Bath	R.T.	10-30 ASF 0.3MIL Tin-Lead
44	Immersion Rinse	1-2 Mins.	Tap Water	R.T.	
45	Spray Rinse	1-2 Mins.	D. I. Water	R.T.	
46	Blow Dry				Use oil free clean dry only.
47	Strip Resist	As Req'd.	Chemline Stripper Q-293	R.T.	
48	Immersion Rinse	1-2 Mins.	Tap Water	R.T.	
49	Strip Resist	As Req'd	Chemline Stripper Q-293	R.T.	
50	Alkaline Soak	As Req'd.	5% Wyandotte Nuvat	120±20°F	
51	Immersion Rinse	1-2 Mins.	Tap Water	R.T.	
52	Spray Rinse	1-2 Mins.	D.I. Water	R.T.	

TABLE 5: CONTINUED

STEP	PROCESS	TIME	SOLUTION	TEMP	REMARKS
53	Blow Dry				Use clean dry air.
54	Touch-up	As Req'd			
55	Copper Etch	As Req'd	Alkaline Etch	120±20°F	
56	Acid Dip	30±10 Sec.	Chromic/Sulfuric Acid	R.T.	
57	Immersion Rinse	1-2 Mins.	Tap Water	R.T.	
58	Fluoboric Acid	1-2 Mins.	10% HBF_4	R.T.	
59	Immersion Rinse	1-2 Mins	Tap Water	R.T.	
60	Strip Touch-up	As Req'd.	Chemline Stripper		Use clean Stripper solution.
61	Ammonium Persulfate Dip	1-2 Mins.	15% Ammonium Persulfate	R.T.	
62	Immersion Rinse	1-2 Mins.	Tap Water		
63	Spray Rinse	1-2 Mins.	D.I. Water		
64	Blow Dry				Use clean dry air.
65	Route				

TABLE 5: CONTINUED

STEP	PROCESS	TIME	SOLUTION	TEMP	REMARKS
66	Fluoboric Acid	1-2 Mins.	10% HBF_4	R.T.	
67	Immersion Rinse	1-2 Mins.	Tap Water	R.T.	
68	Alkaline Clean	1-2 Mins.	NUVAT Solution	140±20°F	
69	Immersion Rinse	1-2 Mins.	Tap Water		
70	Spray Rinse	1-2 Mins.	D.I. Water		
71	Flux Board	20-30 Sec.	Lectrochem Flux #207		
72	Oil Fuse	20-30 Sec.	Lectrochem Fusing Oil #2107	225±10°C	
73	Fusing Oil Freeze Bath	20-30 Sec.	Lectrochem Fusing Oil #2107	R.T.	
74	Hot-Water Rinse	30-60 Sec.	Tap Water		
75	Blow Dry				Use oil free clean dry air.
76	Boards Fabricated from the Unclad Adhesively Coated Material must be subsequently cleaned in Freon TMC for 1-3 minutes.				

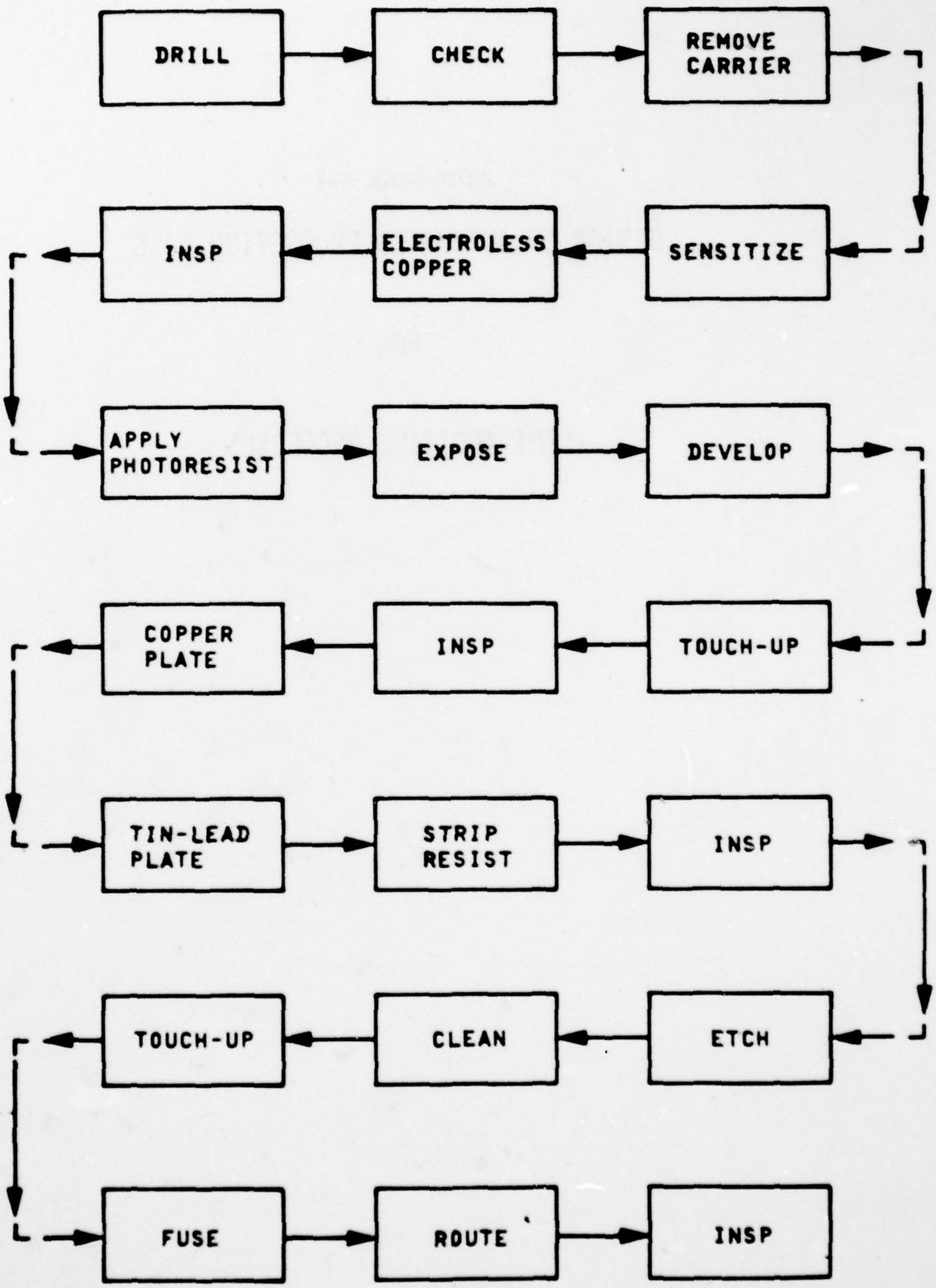
APPENDIX B-4

DESIGN OF AUTOMATED PRODUCTION LINE

FOR

SEMI-ADDITIVE PROCESSES

PROCESS FLOW CHART FOR THE FABRICATION OF PWB'S USING ULTRATHIN COPPER CLAD MATERIAL



AD-A075 975 HUGHES AIRCRAFT CO FULLERTON CALIF F/G 9/1
SEMI-ADDITIVE PROCESSES FOR FABRICATION OF PRINTED WIRING BOARD--ETC(U)
JUN 79 J QUINTANA DAAK01-76-C-1100
UNCLASSIFIED FR 79-12-190 NL

2 OF 2
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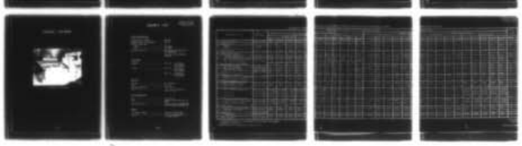

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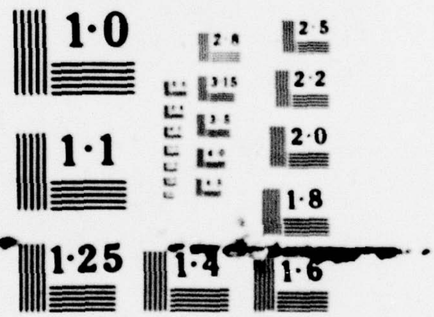
NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

Process Specification Master List

For Semi-Additive Fabrication

Process Specification Master List

For Semi-Additive Fabrication

(Continued)

See electroless line for general tank specifications. This line is controlled by the 9640A multiprogramming system (see p. 21), which enables various programs to be stored which control the automatic hoist operation. This automatic system regulates the sequences in which the hoist processes boards through the various solutions and rinses, as well as controlling the time in each tank. The current in the plating tanks is also controlled by this programming. A remote station, seen on p. 19, enables platers on the line to call and initiate various programs. A diagram of the hoist is given on p. 22, and it is shown in operation on p. 23.

Process Specification Master List

For Semi-Additive Fabrication

(Continued)

Process Specification Master List

For Semi-Additive Fabrication

(Continued)

Process:		Ref. Page
Tank		
25	Tap water rinse, overflow..................	B-63
26	D.I. water rinse, spray....................	B-64
27	Sulfuric acid................................	B-63
28	D.I. water rinse, spray....................	B-64
29	Ammonium persulfate etch..................	B-63
30	D.I. water rinse, spray....................	B-61
31	Fluoboric acid...............................	B-63
32	Tin lead plate...............................	B-65
33	Tap water rinse, overflow..................	B-63
34	D.I. water rinse, spray....................	B-64
35	Dryer..	B-66
Resist Strip	....	B-67, B-68
Stripper recovery still	....	B-69
Touch-up	....	None
Copper etch	....	B-70, B-71
Touch-up	....	None
Solder fusion	....	B-72, B-73
Cleaner/Scrubber	....	B-74, B-75
Router	....	B-76, B-77

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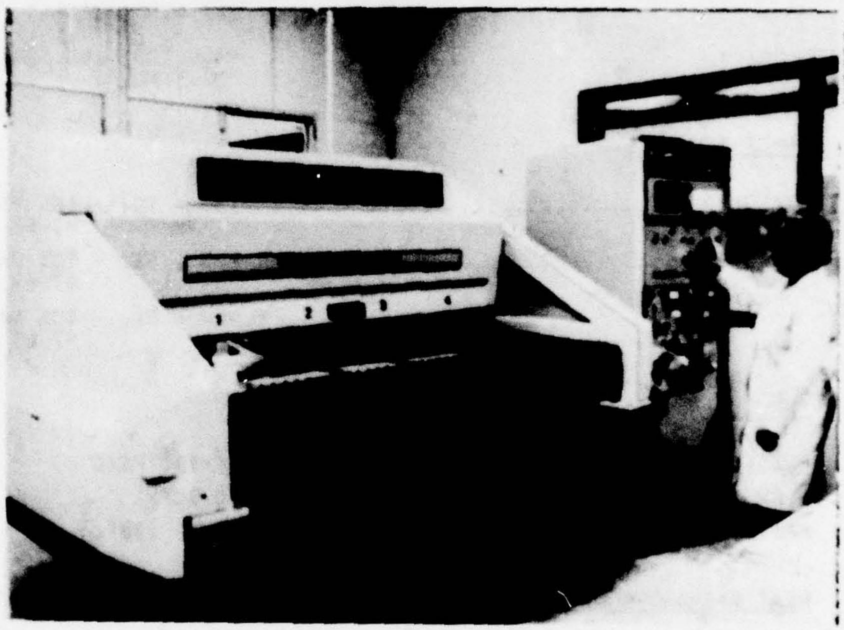
Hughes Aircraft Company
Fullerton, California

EXCELLON MARK 4 DRILL



Excellon Mark 4 Drill

EXCELLON MARK IV DRILL

WEIGHT AND SPACE DATA

SHIPPING WEIGHT (APPROX)	9000 LBS*
SEPARATE WEIGHT OF CNC CONSOLE	450 LBS
REQUIRED FLOOR SPACE:	
LENGTH	14.3 FEET
WIDTH	13.6 FEET
MAXIMUM FLOOR LOAD	600 PSI WITH FOOT BOLT PADS (27 ATMOSPHERES)
	*ADD 1000 LBS FOR OVERSEAS CRATING.

INPUT POWER

STANDARD	230 + 5%, - 10% VAC, 30A, 47-63 Hz
OPTIONS	208 + 5%, - 10% VAC, 30A, 47-63 Hz
	460 + 5%, - 10% VAC, 15A, 47-63 Hz

INPUT AIR

PRESSURE	95-150 PSIG
FLOW	20 SCFM
MAXIMUM TEMPERATURE	100°F (38°C)

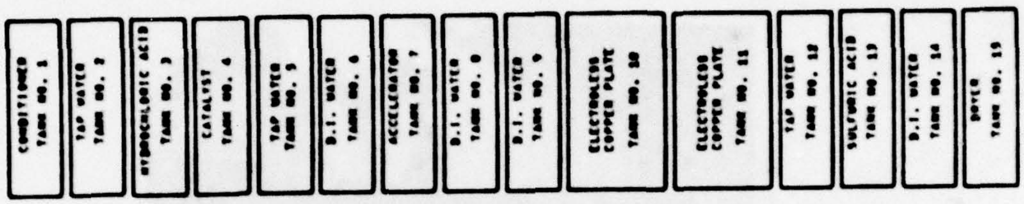
HEAT EXCHANGER DATA

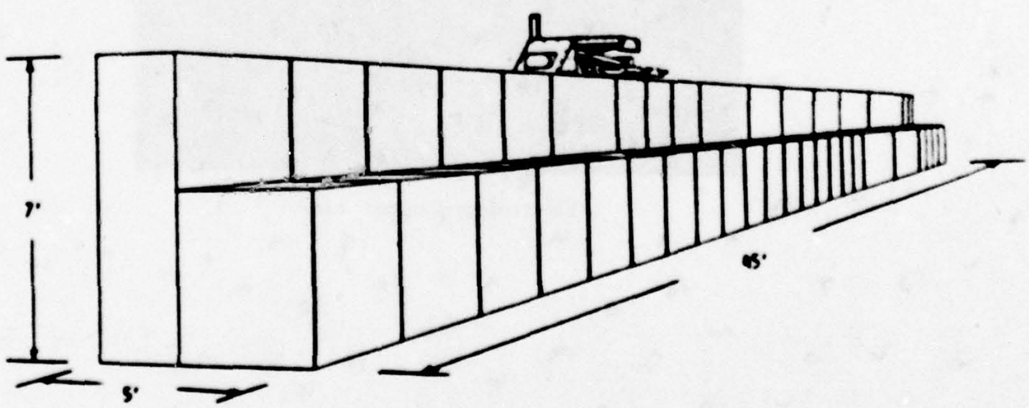
TYPE	FLUID-TO-AIR
MEDIA	CORROSION-INHIBITED DISTILLED WATER
PRESSURE AND FLOW	15 PSI AT 37 TO 44 GALLONS PER HOUR (3-SPINDLE CONFIGURATION)
CHIP REMOVAL METHOD	VACUUM AT PRESSURE FOOT
VACUUM CRITERIA	120 CFM, 16 INCH WATER LIFT, 1.5 INCH ORIFICE

ELECTROLESS COPPER LINE

Electroless Copper Line

AUTOMATED ELECTROLESS COPPER LINE





ELECTROLESS LINE
PROCESS TANK

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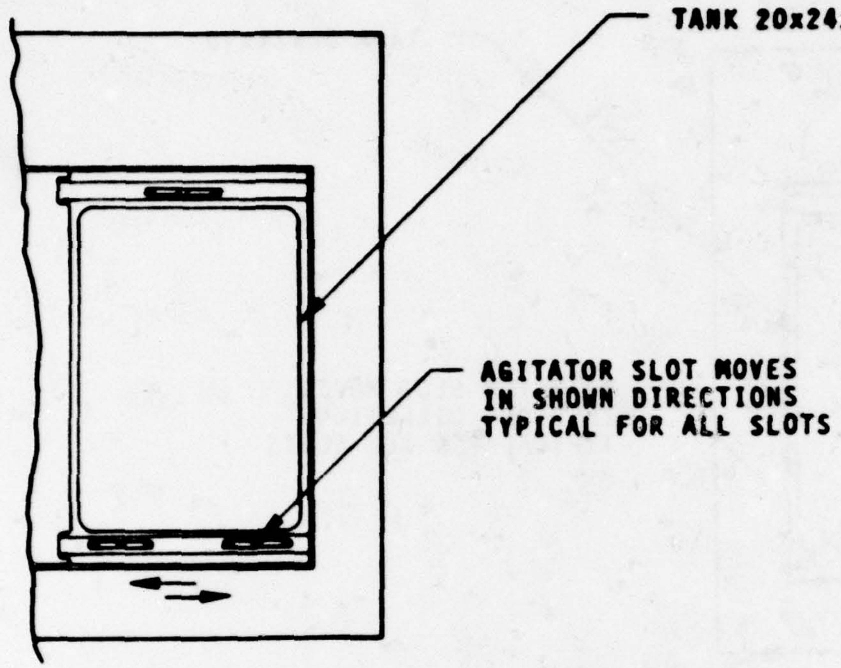
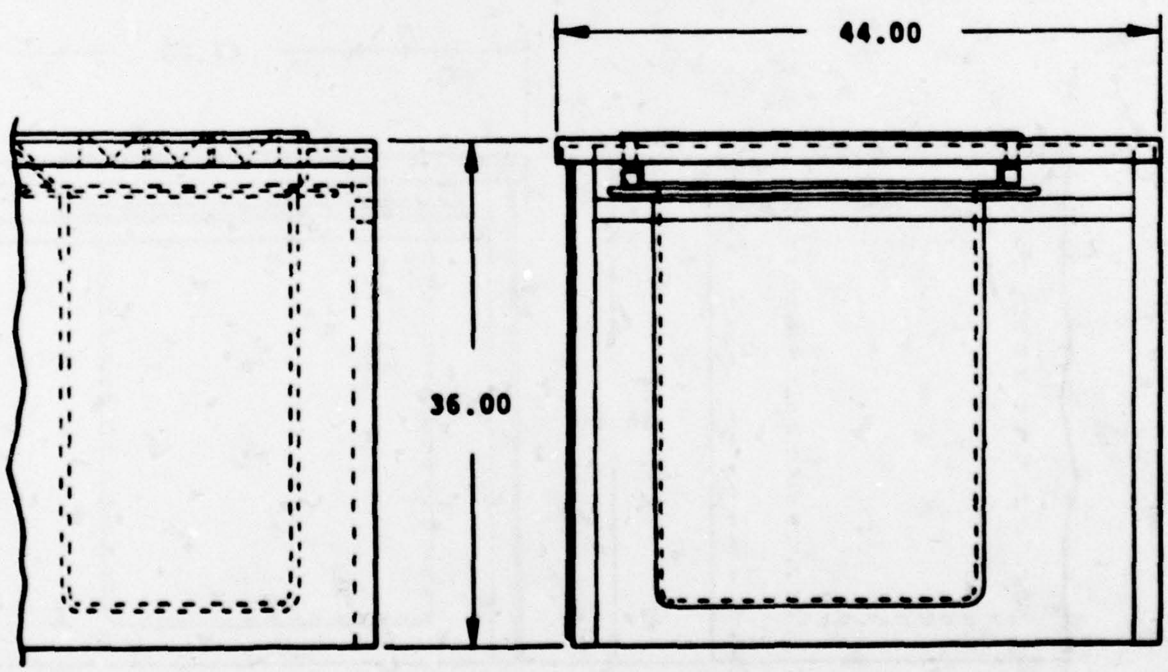
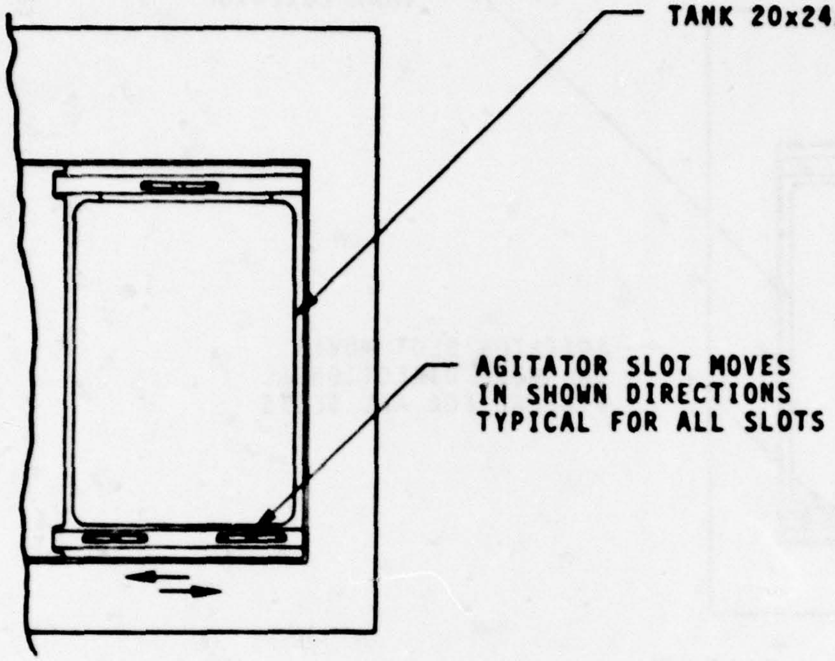
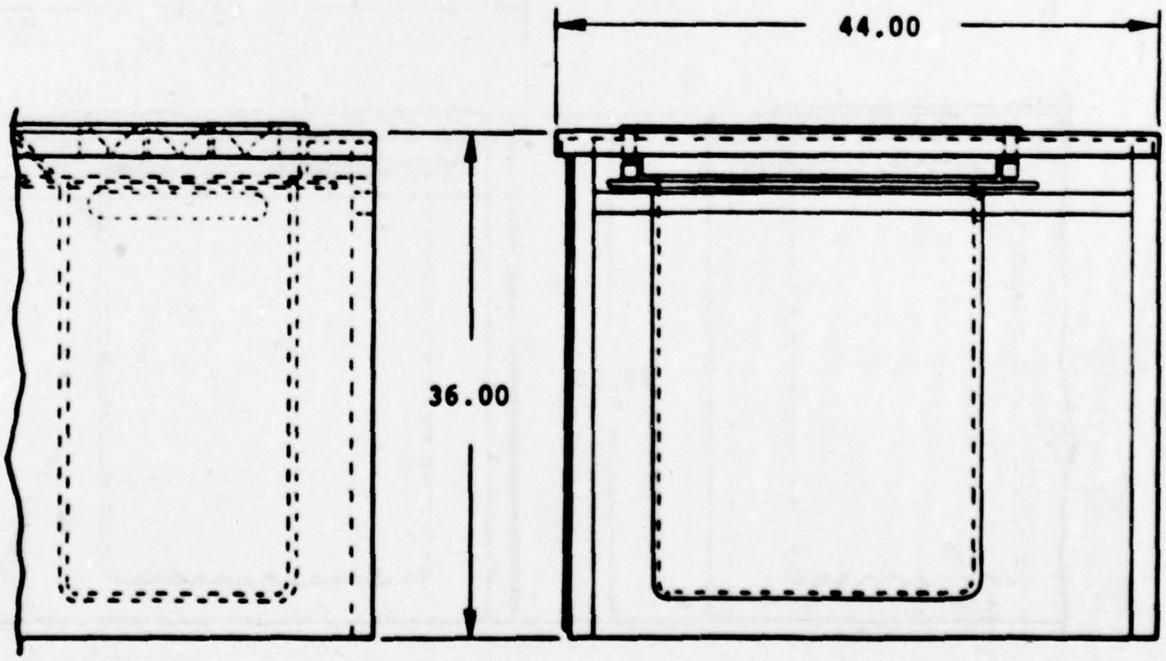




ELECTROLESS LINE
OVERFLOW RINSE





ELECTROLESS LINE
SPRAY RINSE TANK

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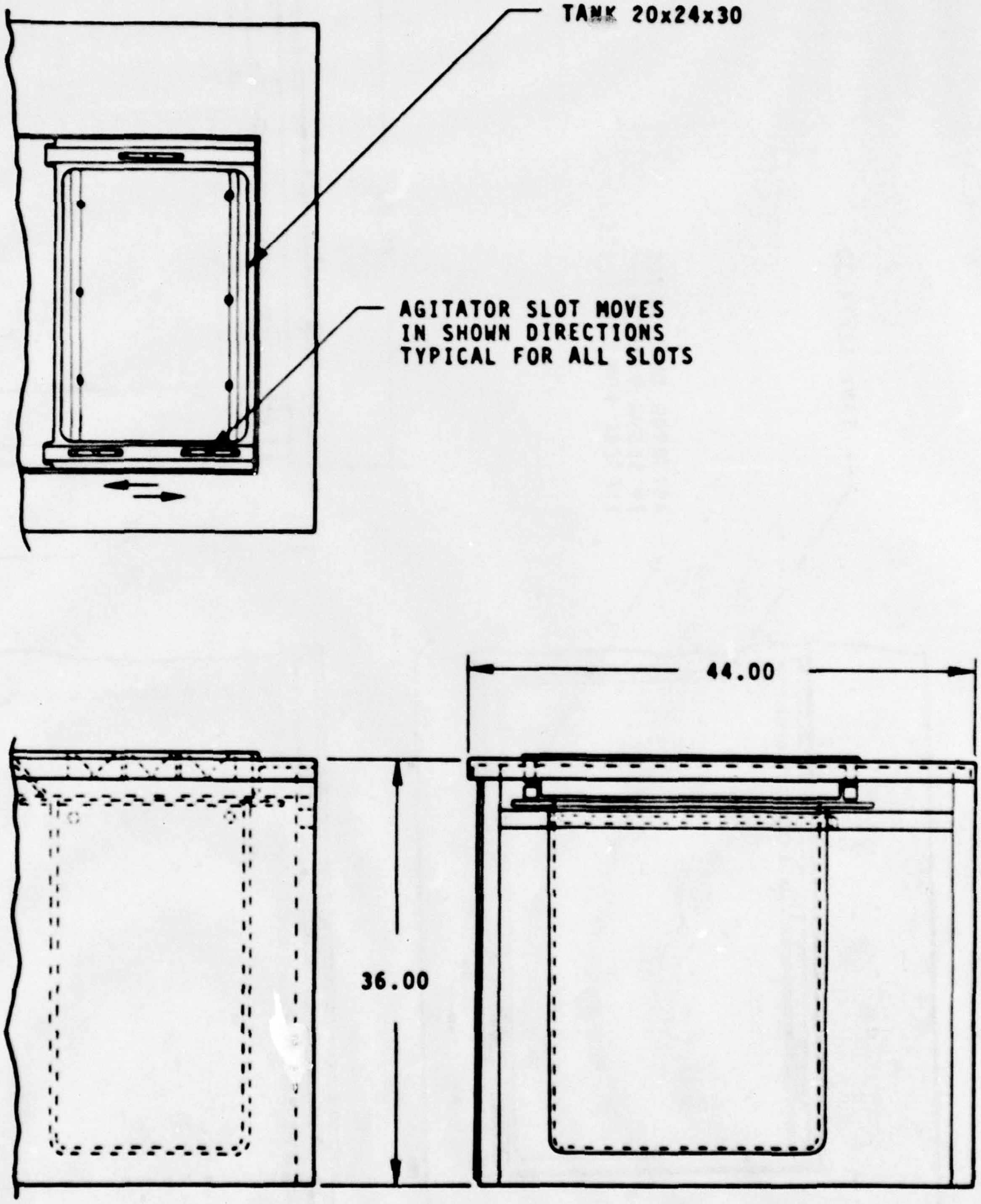
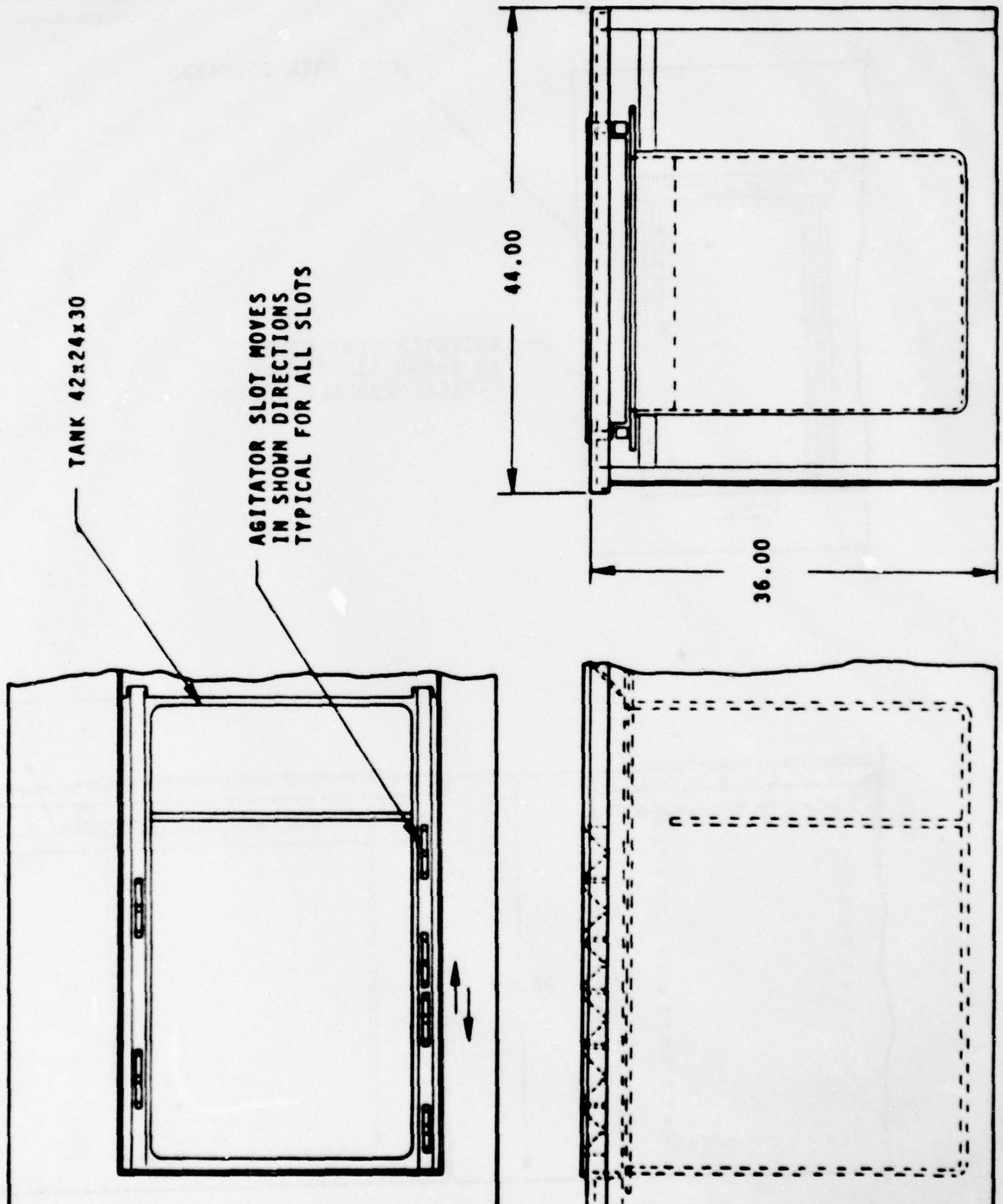


ELECTROLESS
LINE ELECTROLESS
COPPER TANK



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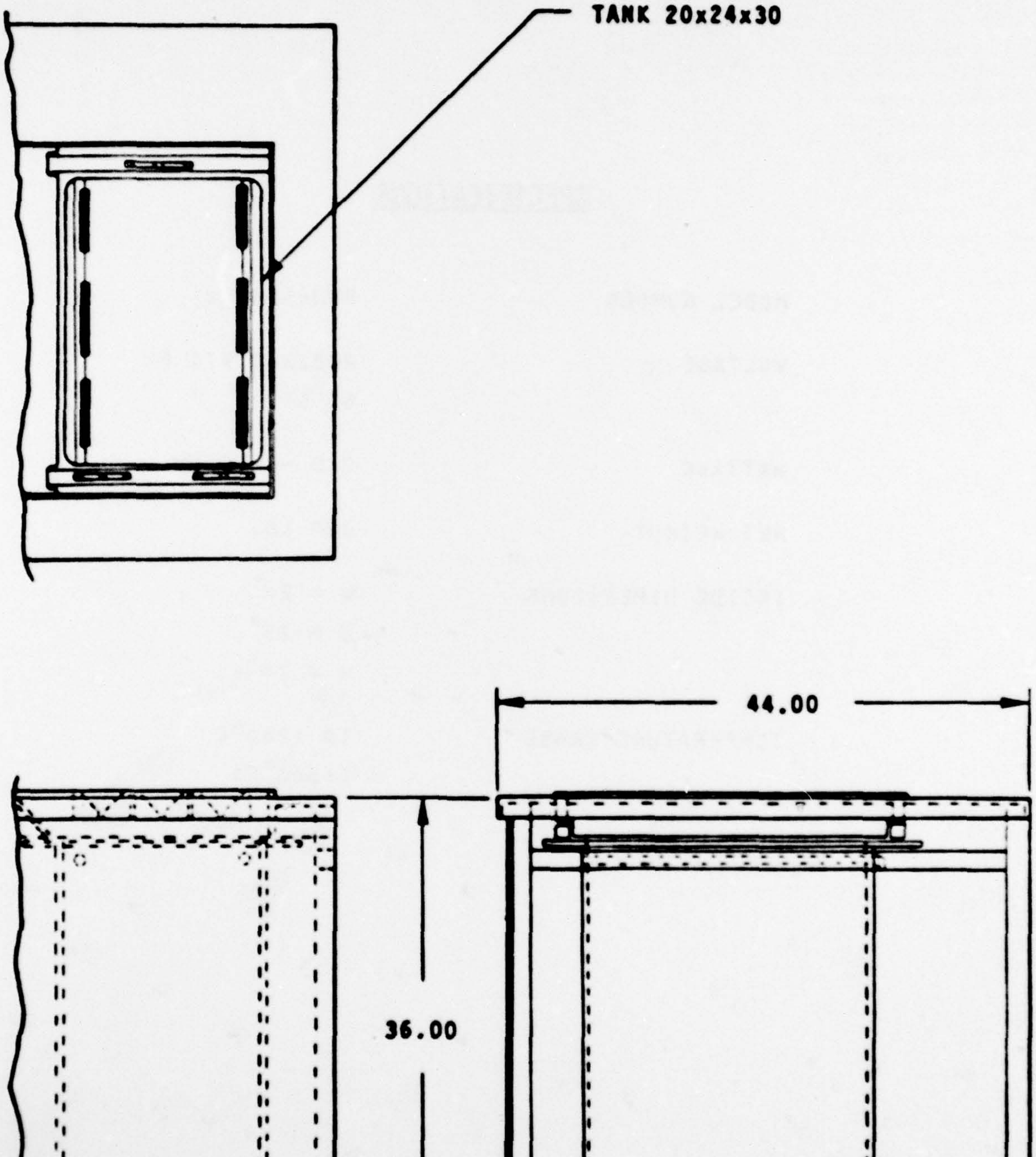
ELECTROLESS LINE
DRYER



BLUE M BATCH OVEN

SPECIFICATIONS

MODEL NUMBER	POM-588C-2
VOLTAGE	208/240 V/1 Ph 60 CY
WATTAGE	3.0 - 4.0 KW
NET WEIGHT	300 LB.
INSIDE DIMENSIONS	W = 24" D = 25" H = 24"
TEMPERATURE RANGE	TO +260°C (+500°F)

PHOTO RESIST APPLICATION

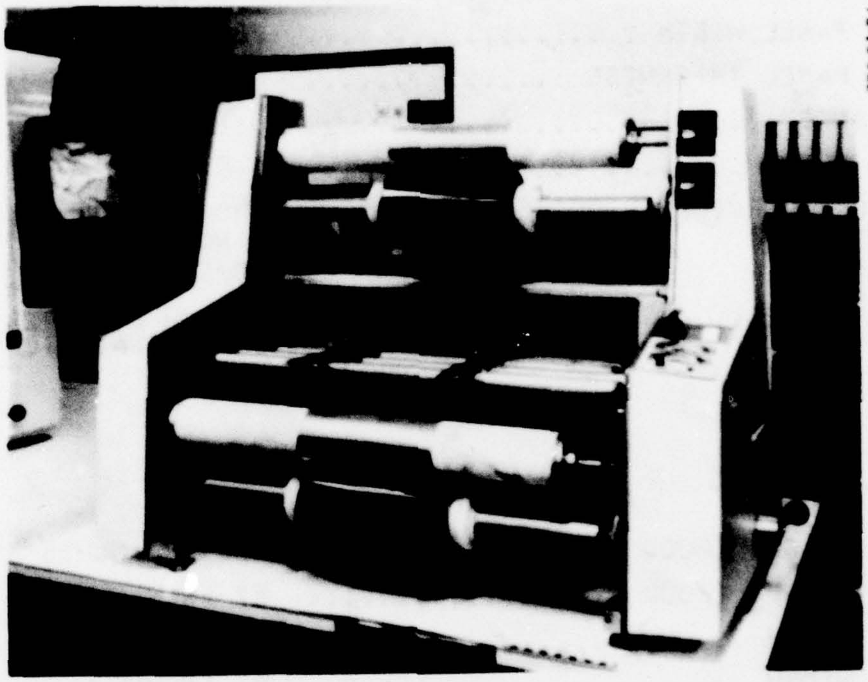


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Photo Resist Application

HOT ROLL LAMINATOR HRL - 24

DIMENSIONS	32.5"W x 23.5"L x 27.25"H
WEIGHT (APPROX)	175 lbs
SHIPPING WEIGHT (APPROX)	225 lbs
HEATER CAPACITY (2)	1000 WATTS EACH
LAMINATING TEMPERATURE	210-220°F
MAXIMUM PANEL WIDTH	26 INCHES
MAXIMUM PANEL THICKNESS	0.250 INCHES
SPEED RANGE	0-13 fpm
WORKING RANGE	5-8 fpm
ELECTRICAL SERVICES REQUIRED	240/200 V SINGLE PHASE 60/50 Hz, 20 A
EXHAUST	3 INCH DIAMETER DUCT CONNECTION

MACHINE ASSEMBLY

OVERALL HEIGHT (HOOD DOWN)	63-3/8 INCHES	
OVERALL HEIGHT (HOOD UP)	87 INCHES	APPROXIMATE
OVERALL DEPTH	76 INCHES	
OVERALL WIDTH	92 INCHES	DIMENSIONS
HEIGHT TO TOP OF WORKTABLE	37 INCHES	

CONTROL CONSOLE

HEIGHT	71 INCHES
DEPTH	33 INCHES
WIDTH	22 INCHES
HEIGHT TO UPPERMOST CONTROLS	63 INCHES

PHOTORESIST EXPOSURE

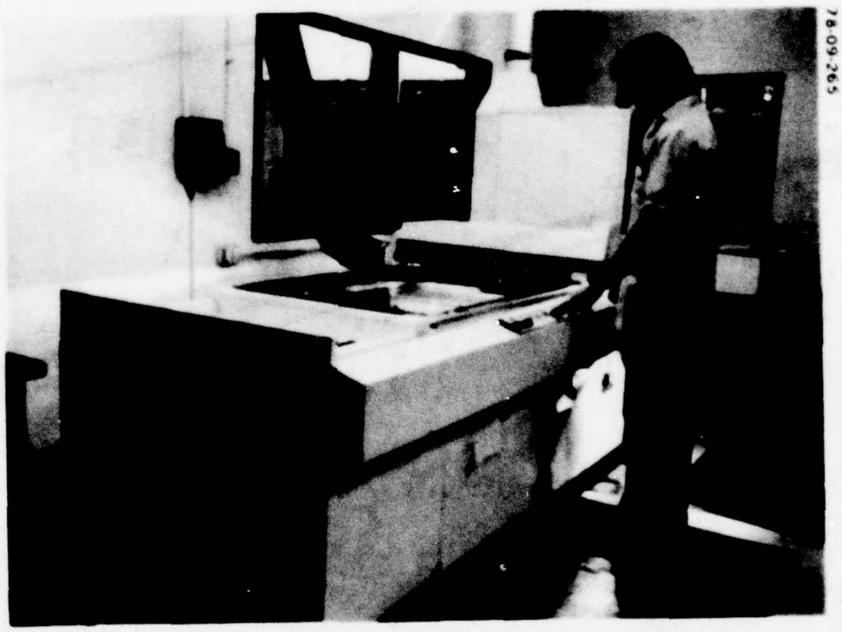
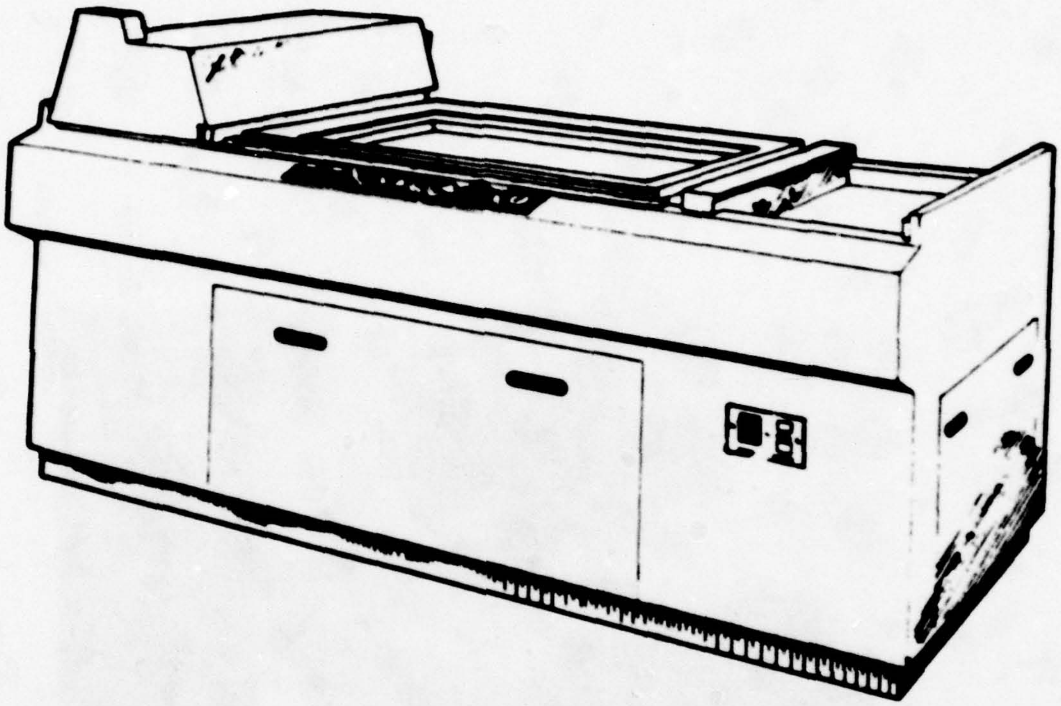


Photo Resist Exposure

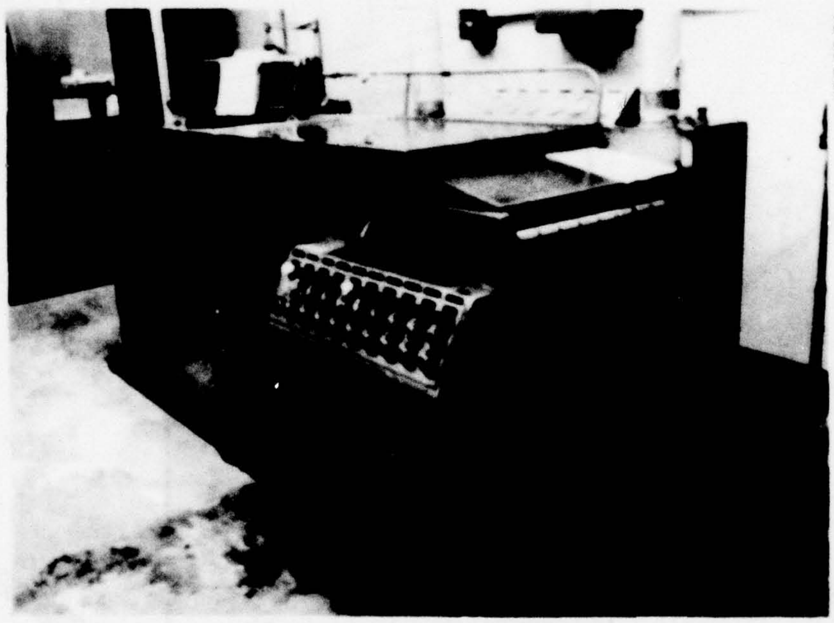
COLIGHT EXPOSURE MACHINE



SPECIFICATIONS

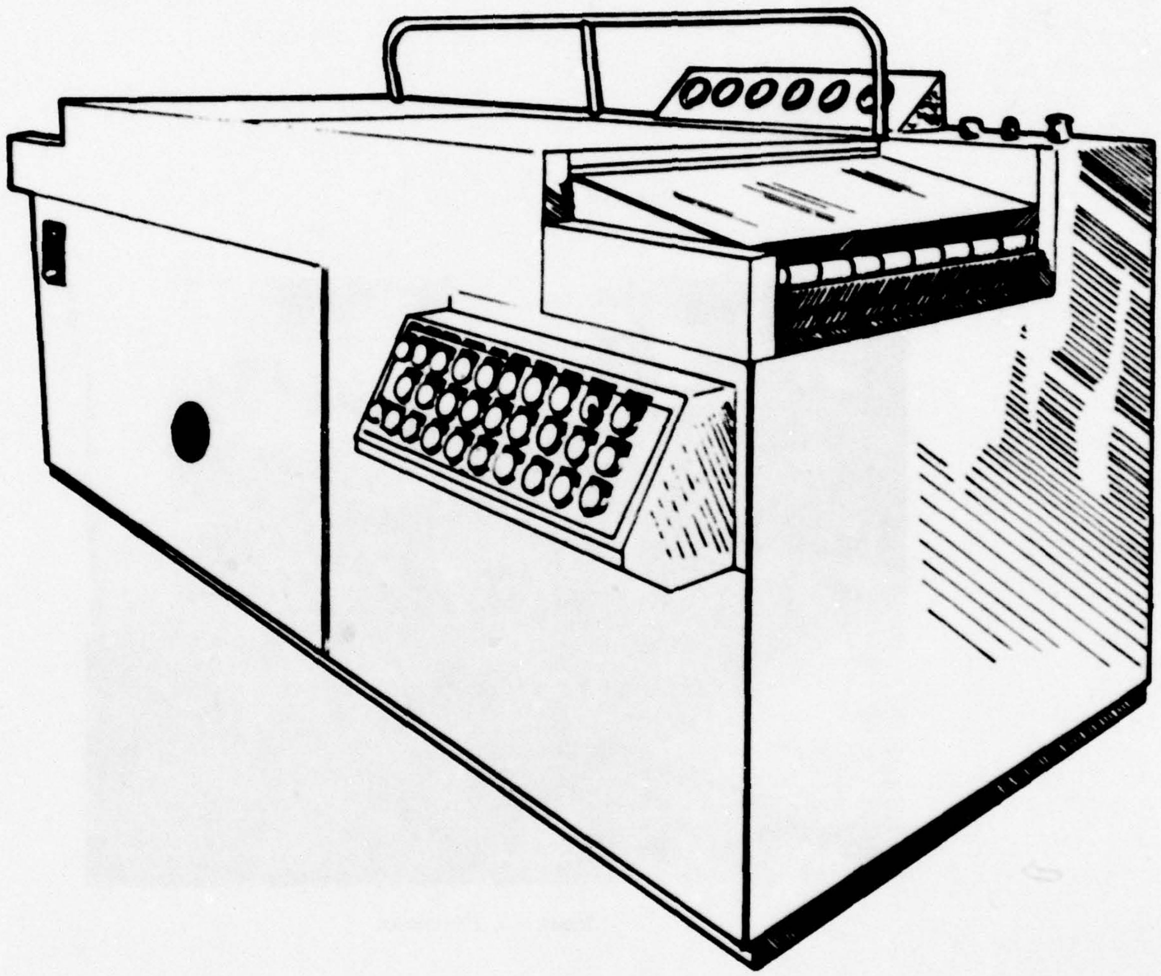
EXPOSURE AREA	30" X 40" DOUBLE SIDED
ELEC. REQUIREMENTS	230 VOLTS, 60 Hz, 60 AMP, 1 PHASE
LAMPS	(2) 4800 WATT, AIR COOLED, MERCURY VAPOR
LAMP LIFE	1500 HOURS
VACUUM PUMP	ROTARY 5.8 CFM 1/3 H.P.
EXHAUST BLOWER	1 H.P., 1500 CFM (FREE AIR)
CABINET SIZE	LENGTH 90", DEPTH 46", HEIGHT 43"
SHIPPING WEIGHT	1700 LBS

RISTON C-PROCESSOR

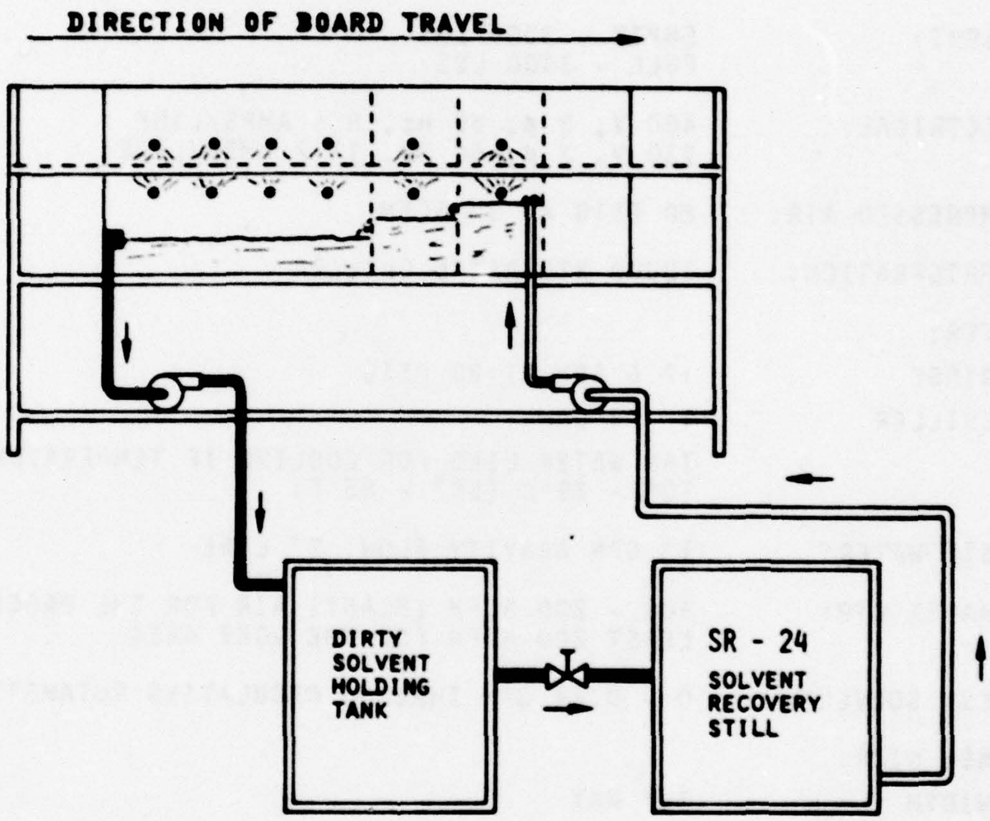


Riston C-Processor

RISTON C - PROCESSOR



RISTON C - PROCESSOR



RISTON C - PROCESSOR

SPECIFICATION

DIMENSIONS:	105" L X 45" W X 48" H
WEIGHT:	EMPTY - 3000 LBS FULL - 3400 LBS
ELECTRICAL:	460 V, 3 ø, 60 Hz, 8.6 AMPS/LINE 230 V, 3 ø, 60 Hz, 17.2 AMPS/LINE
COMPRESSED AIR:	80 PSIG AT 30 SCFM
REFRIGERATION:	12000 BTU RATED CHILLER
WATER:	
RINSE	12.6 GPM AT 20 PSIG
CHILLER	1 - 3 GPM
	TAP WATER USED FOR COOLING IF TEMPERATURE RANGE IS 10° - 29°C (50° - 85°F)
WASTE WATER:	13 GPM GRAVITY FLOW, 2" LINE
EXHAUST AIR:	100 - 200 SCFM (PLANT) AIR FOR THE PROCESSOR AND AT LEAST 200 SCFM FOR THE WORK AREA
FRESH SOLVENT:	0 - 0.24 GPM THROUGH REGULATING ROTAMETER
PANEL SIZE:	
WIDTH	24" MAX
THICKNESS	0.25" MAX
MINIMUM	4" X 6"
CONVEYOR SPEED:	26 FPM - (ADJUSTABLE)
RECOMMENDED WORK SPACE:	3' ON ALL SIDES

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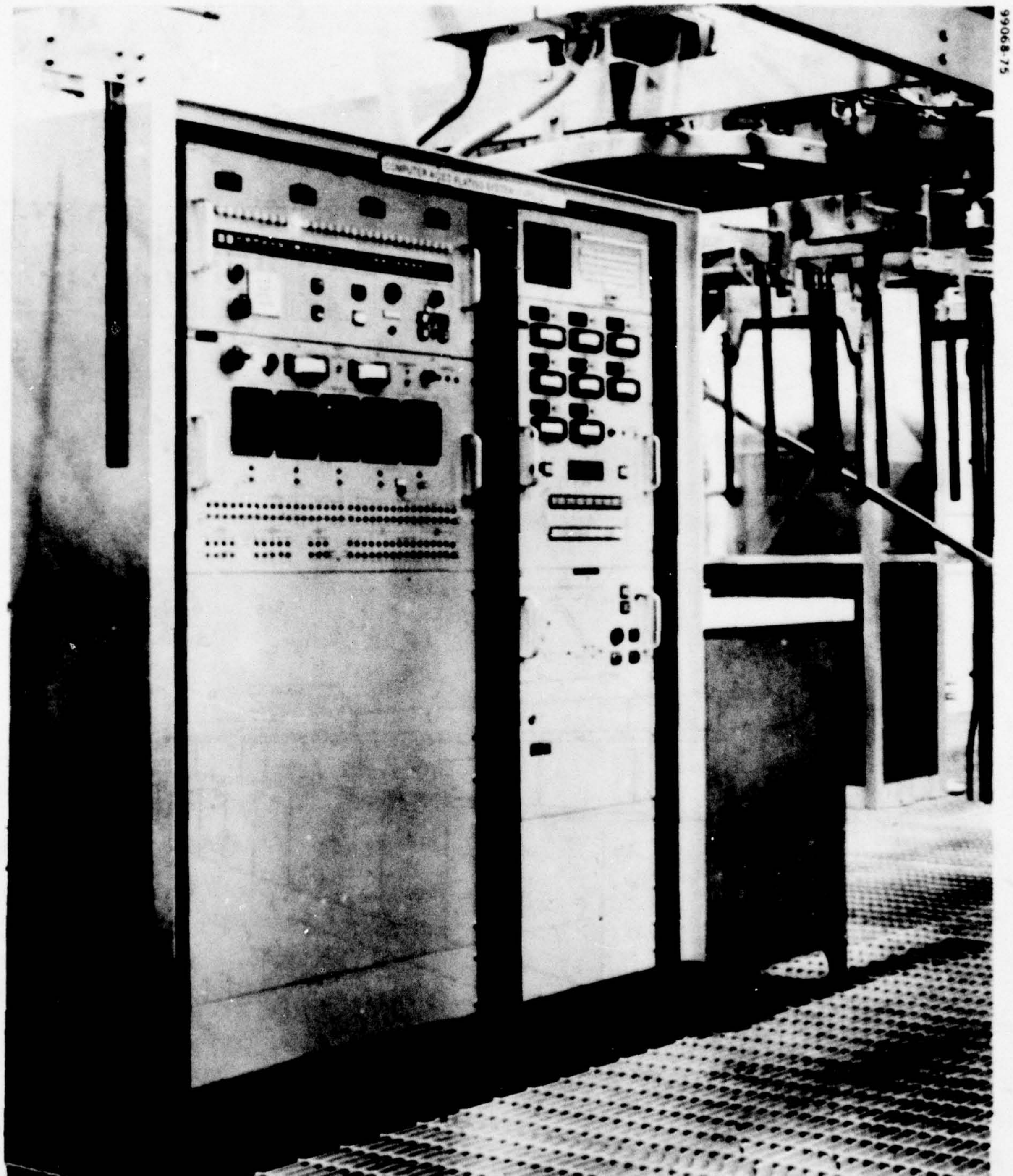
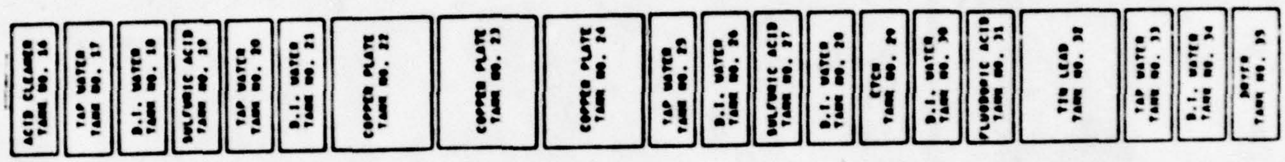
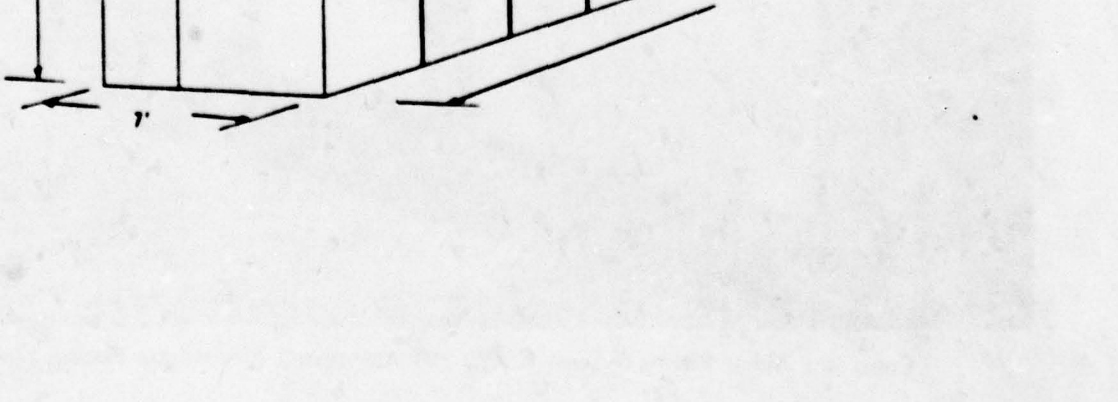
COMPUTER AIDED PLATING SYSTEM (CAPS IV)
AUTOMATED ELECTROLYTIC PLATING LINE



Computer Aided Plating System (CAPS IV) Automated Electrolytic Plating Line

AUTOMATED ELECTROLYTIC COPPER LINE





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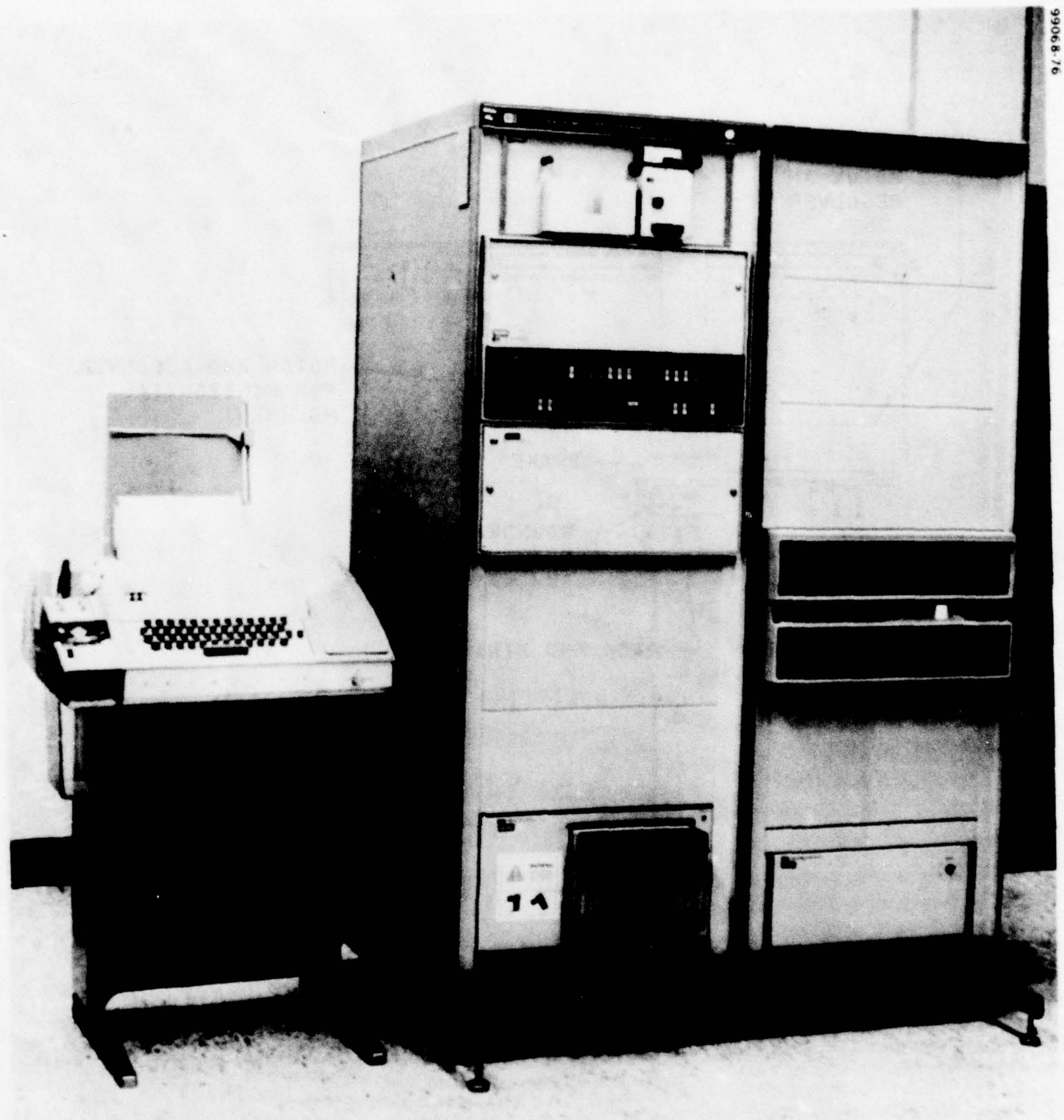
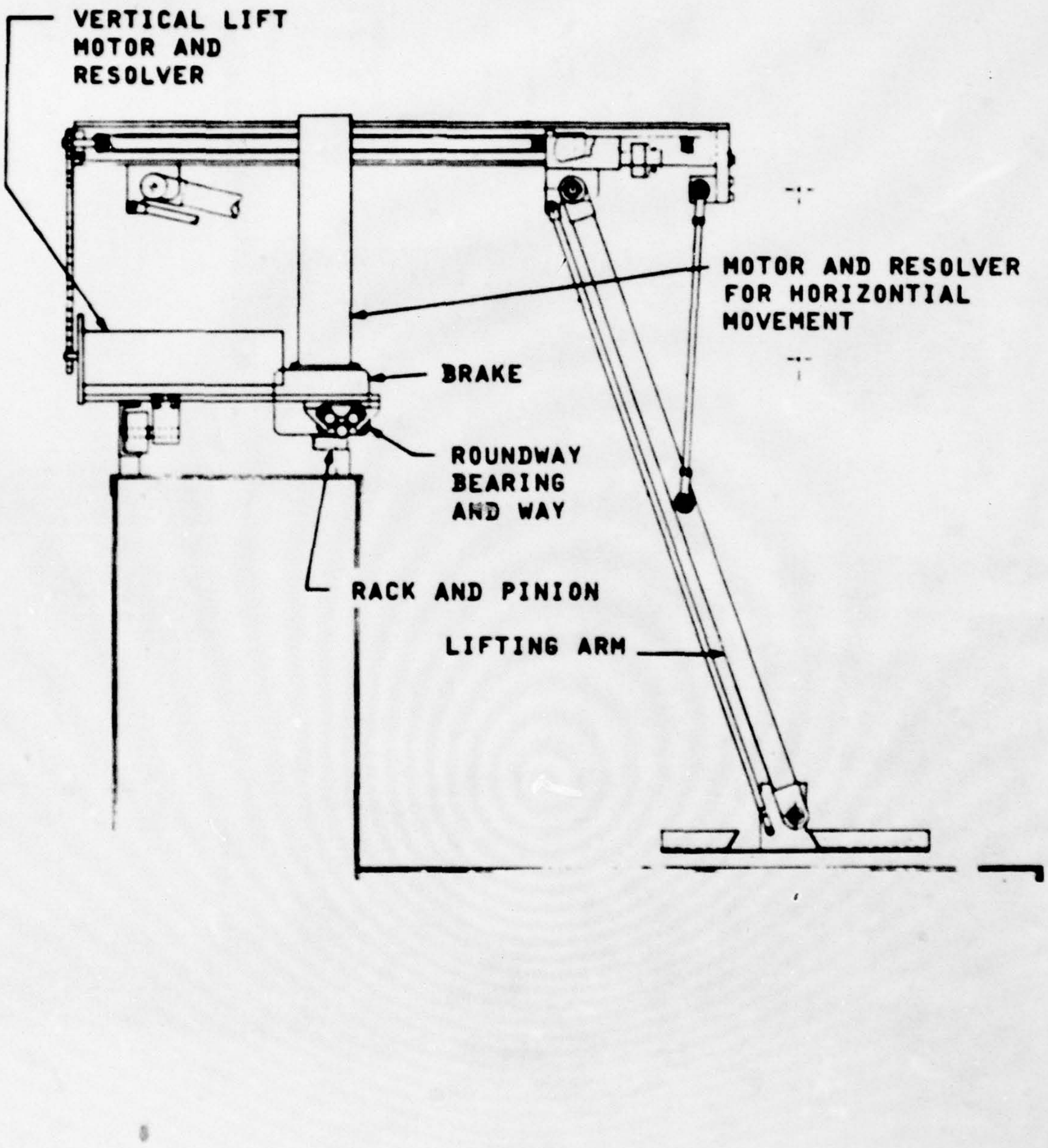
Fullerton, California

9640A MULTIPROGRAMMING SYSTEM



9640A Multiprogramming System

AUTOMATIC LINE HOIST



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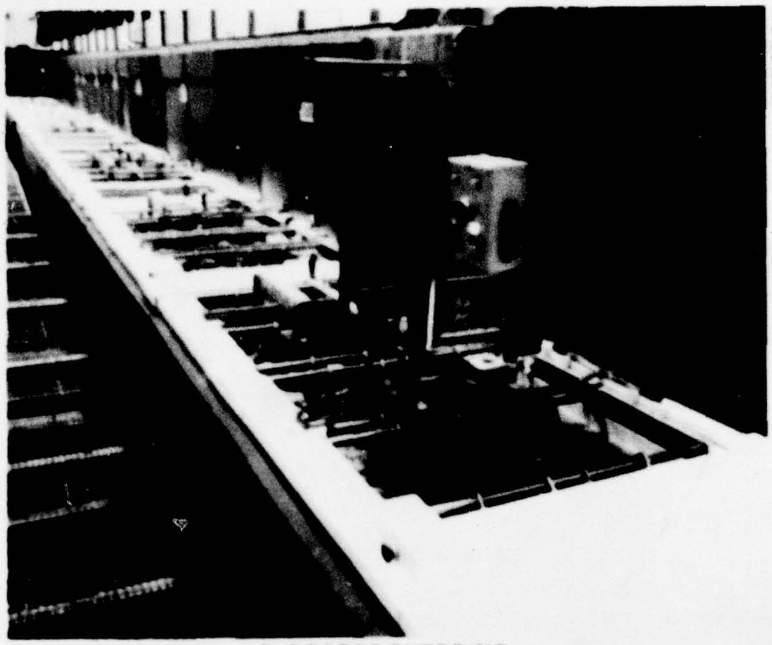
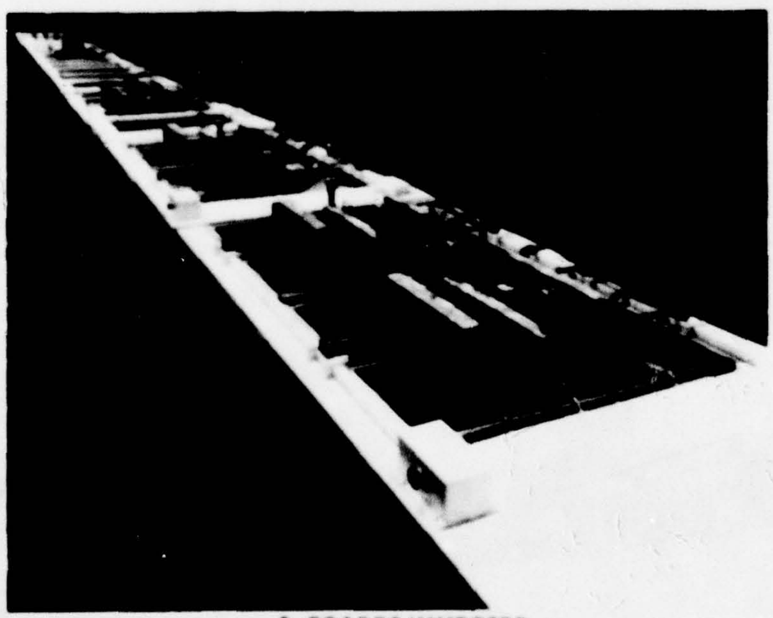
CAPS IV ELECTROLYTIC PLATING LINE

99068-77



1. BOARDS ENTERING
COPPER TANK



2. BOARDS IMMERSED
IN COPPER TANK

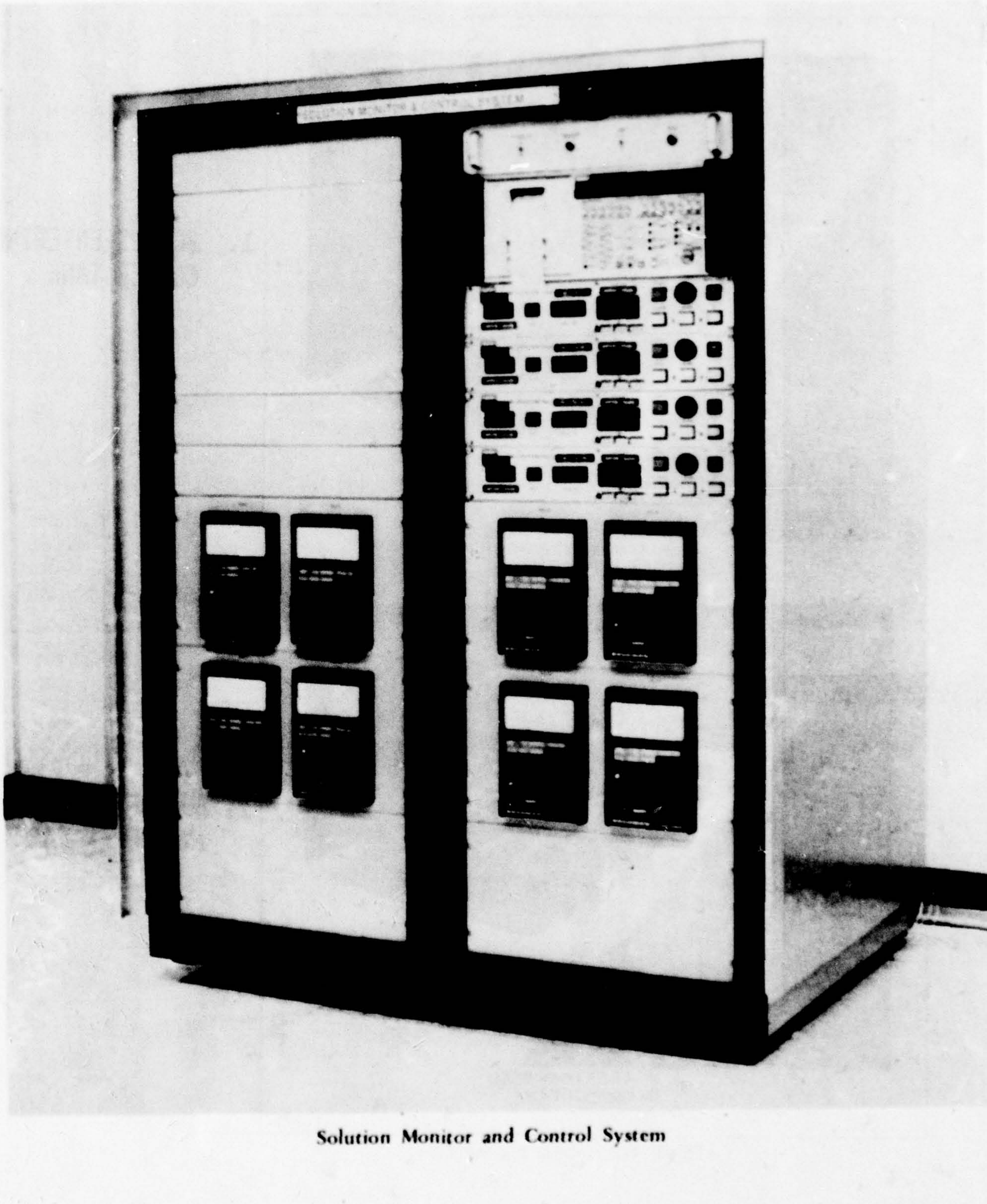
CAPS IV Electrolytic Plating Line

1. BOARDS ENTERING COPPER TANK

2. BOARDS IMMERSED IN COPPER TANK

SOLUTION MONITOR AND

CONTROL SYSTEM



Solution Monitor and Control System

PLATING LINE PROCESS TANK

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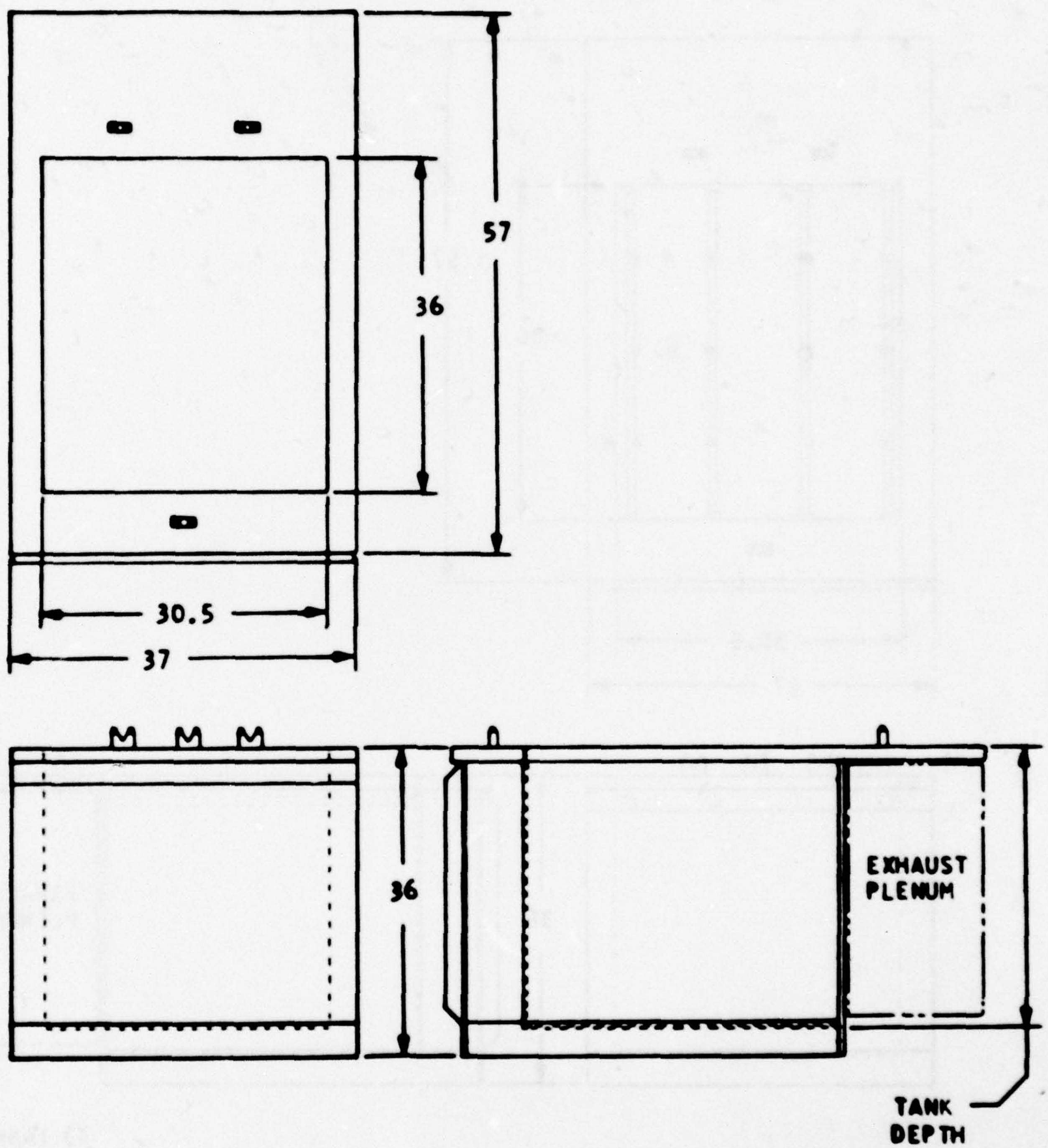
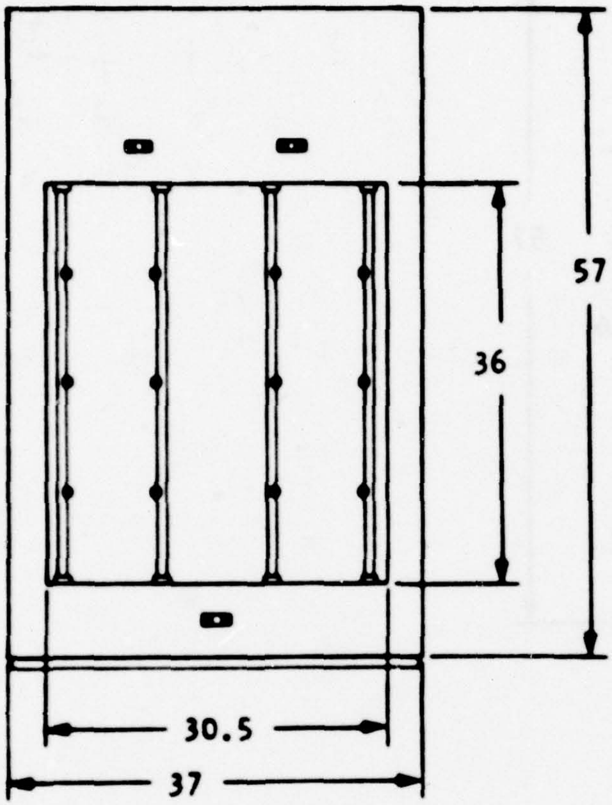
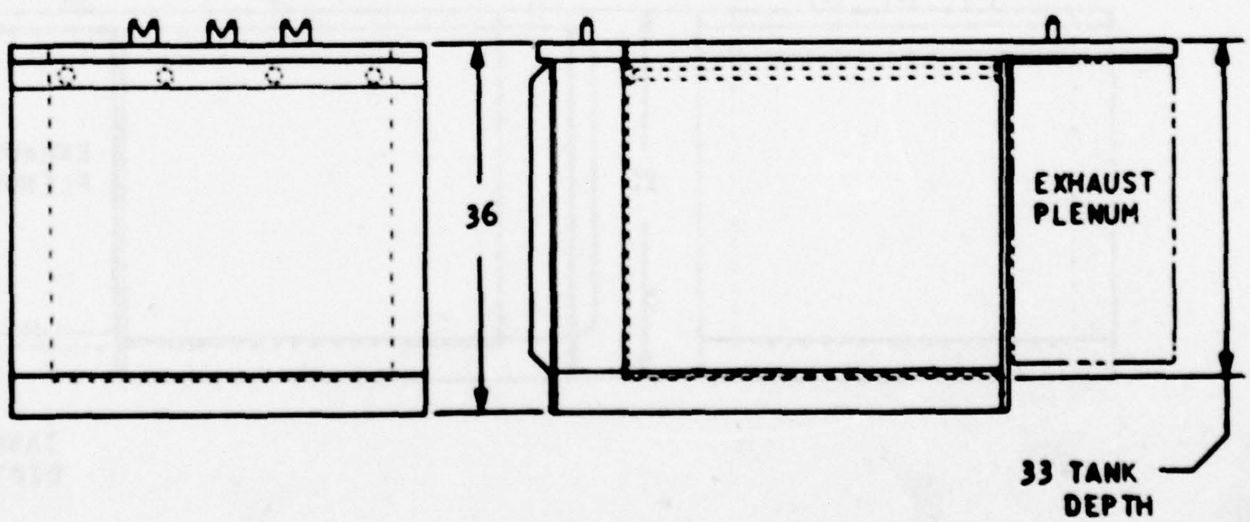



57
36
30.5
37


36
EXHAUST
PLENUM
33 TANK
DEPTH

HUGHES-FULLERTON
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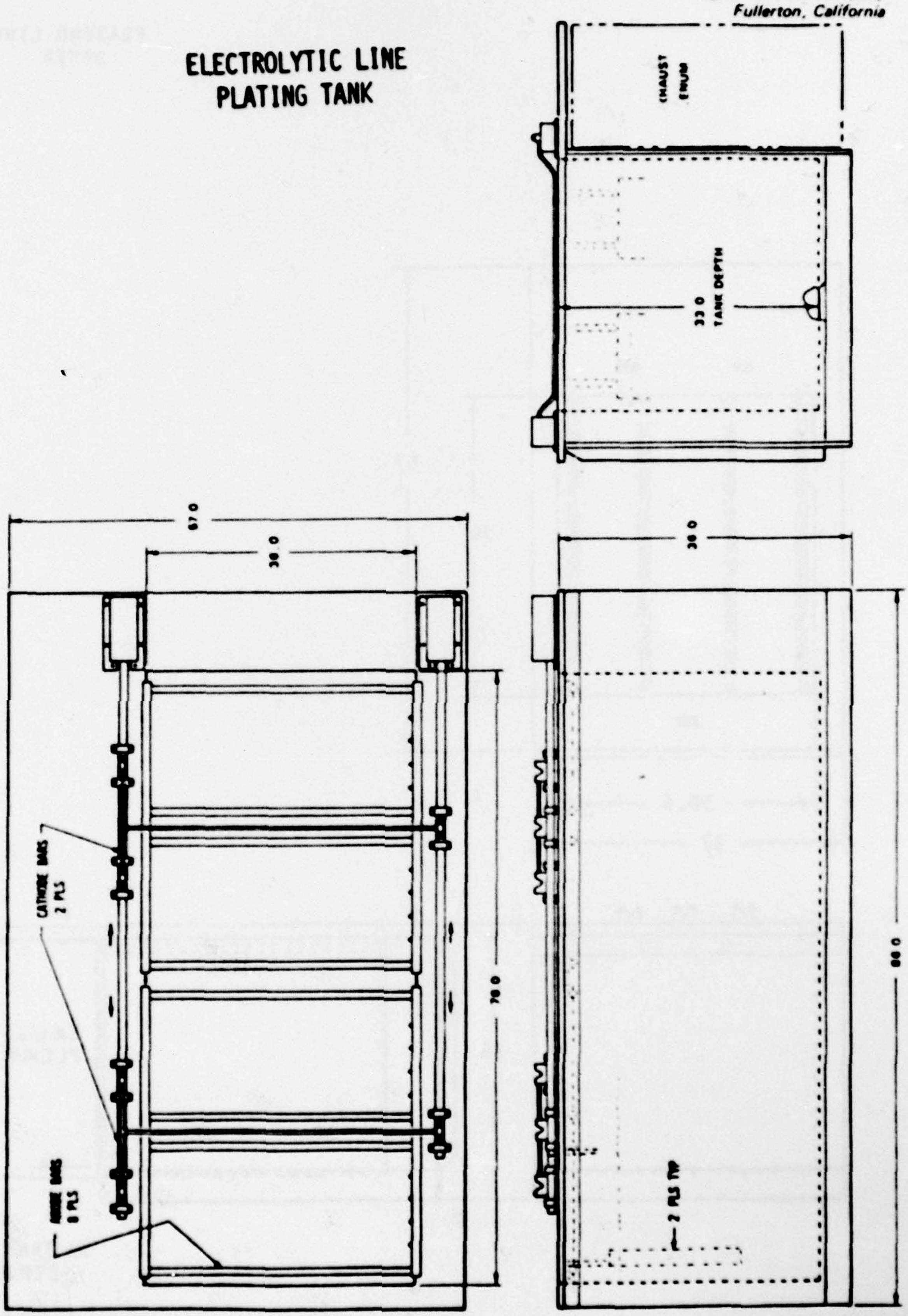
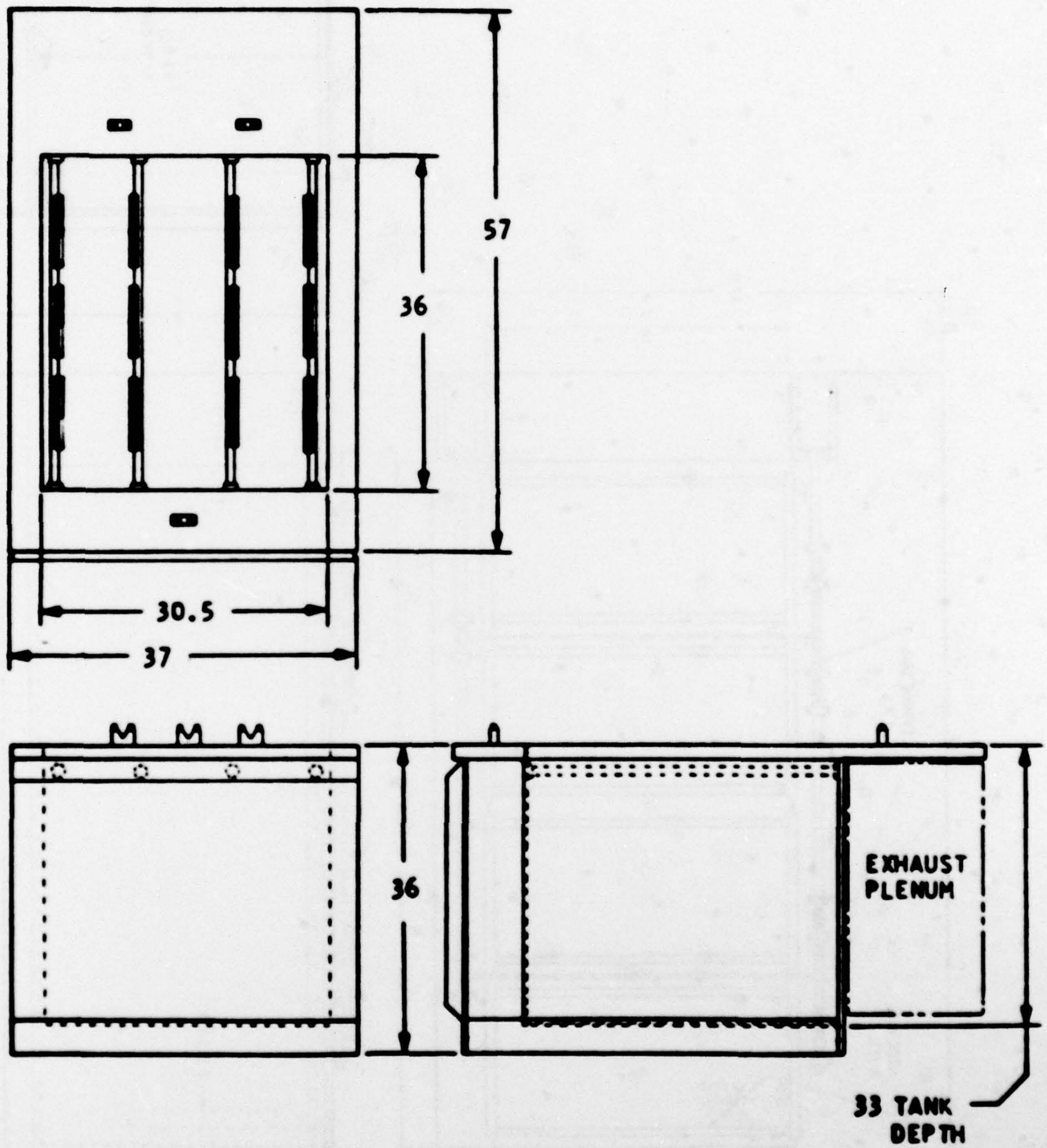
Fullerton, California

ELECTROLYTIC LINE PLATING TANK



PLATING LINE
DRYER



CONVEYORIZED STRIPPER CS - 24

SPECIFICATION:

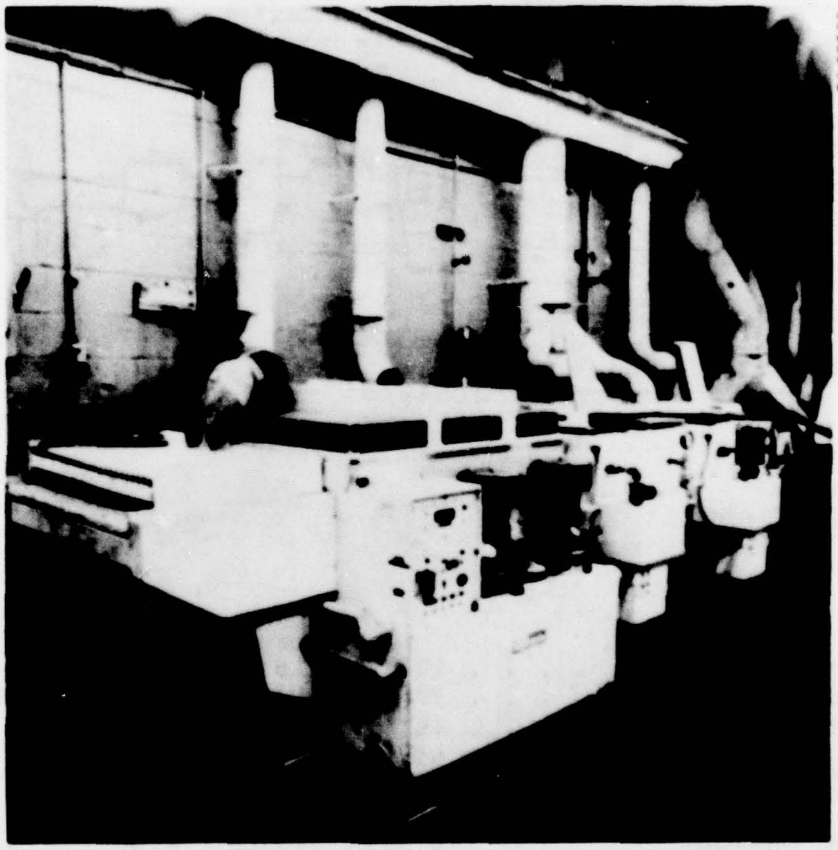
DIMENSIONS	48" L x 76" D x 72" H
WEIGHT	1500 lbs. EMPTY 1700 lbs. CRATED 3300 lbs. FULL
SOLVENT CAPACITY	140 GALLONS
DISTILLATE OUTPUT	120 GPH
COOLING WATER	1200 GPH at 60°F-20°F RISE 2400 GPH at 70°F-10°F RISE PIPING—INLET — 1" NPT OUTLET— 1¼" NPT
ELECTRICAL OPTIONS	230/460V, 3PHASE, 60Hz
HEAT REQUIRED	Plant Steam - 220 lbs./hr. at 6 PSI 2.5/1.3 Amps/ Line (1KVA) Piping - Inlet - 2" NPT NPT Electric Heat Converter Steam - 150/75 Amps/Line (60 KVA)

STRIPPER RECOVERY STILL SRS - 120

SPECIFICATION:

STRIPPER DIMENSIONS	145"L x 57"W x 47"H
CONTROL PANEL	30"W x 10½"D x 60"H (Floor or Wall Mounted)
CONVEYOR HEIGHT	37½"
WEIGHT............................	3000 lbs. EMPTY 3200 lbs. CRATED 5200 lbs. FULL
CONSTRUCTION......................	STAINLESS STEEL
OPERATOR CONTROL STATION..........	MACHINE MOUNTED
SOLVENT CAPACITY.	200 GALLONS
CONVEYOR SPEED....................	0 - 15 FPM
ELECTRICAL OPTION.................	230V, 3PHASE, 60 Hz, 18 Amp/Line (7KVA) 460V, 3PHASE, 60 Hz, 9 Amp/Line (7KVA)
EXHAUST (supplied)	750 SCFM at ½" Static Pressure
MAXIMUM PANEL WIDTH...............	24"
MAXIMUM PANEL THICKNESS...........	.250"

DEA ETCHER



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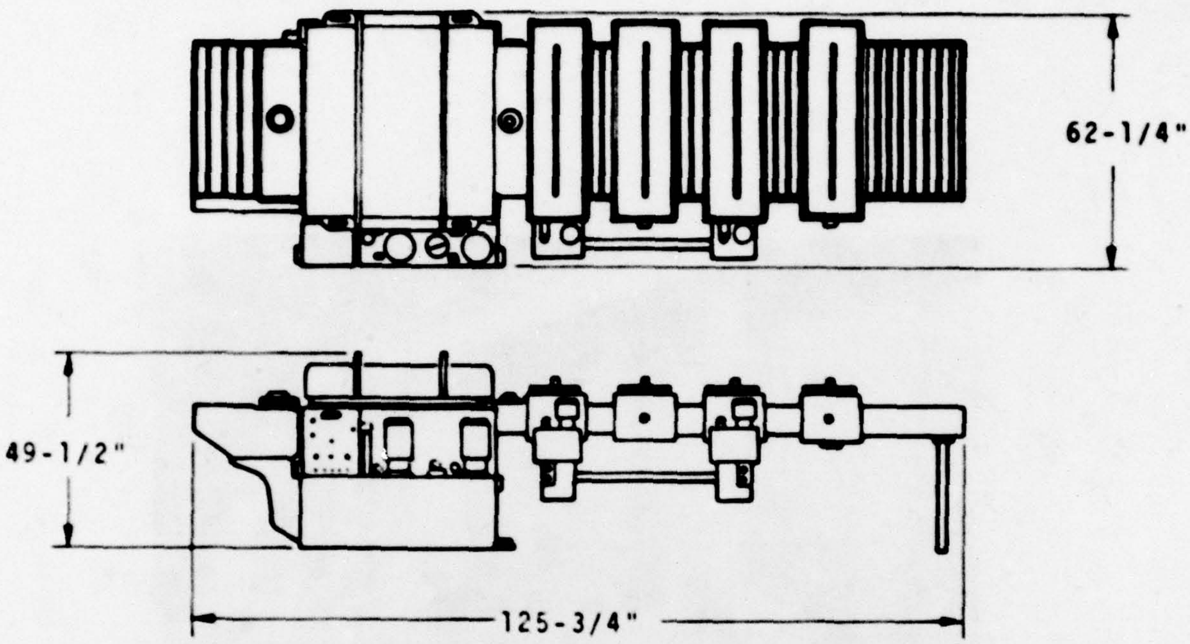
DEA Etcher

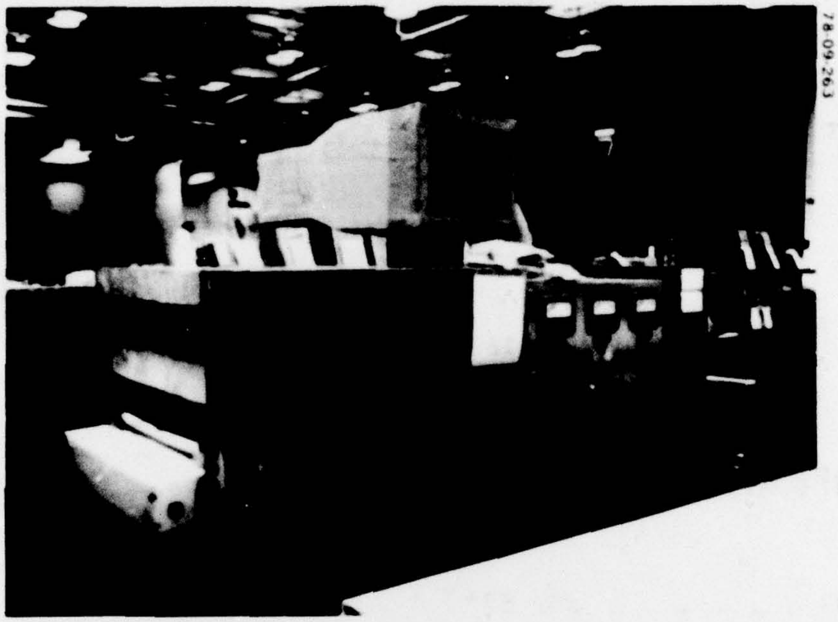
DEA ETCHER



SPECIFICATIONS:

OVERALL DIMENSION	125 3/4"LONG, 62 1/4"WIDE, 49 1/2"HIGH
CONVEYOR WIDTH.	38" NOMINAL, 36" EFFECTIVE
ETCH CHAMBER LENGTH	48" EFFECTIVE
SUMP CAPACITY	65 - 135 GALLONS
SUMP DRAIN	1 1/2" PVC BALL VALVE
LOW LIQUID LEVEL INDICATOR . .	FLOAT ACTUATED SWITCH
TEMPERATURE CONTROL	DIRECT READOUT W/BUILT-IN THERMOSTAT ± 2 F W/AUTOMATIC OVERTEMP PROTECTION AT 140 F
IMMERSION HEATERS	THREE, 4KW QUARTZ TUBE UNITS
PUMPS	TWO, SUBMERSIBLE, CENTRIFUGAL TYPE 1 H.P.
SPRAY REGULATION	INDIVIDUAL EXTERNAL CONTROLS
PRESSURE GAGES.	OPTIONAL
EXHAUST VENT.	VENT PORT BEFORE AND AFTER ETCH CHAMBER
SAFETY INTERLOCK.	MAGNETIC
CONVEYOR CONTROL.	DC SOLID STATE 0-9 FT/MINUTE
BAUME READING	OPTIONAL
POWER REQUIREMENT	208V, 240V, 480V, 60HZ, 3 PHASE 10KW
MAXIMUM BOARD SIZE.	24" WIDE - ANY LENGTH
HOT WATER CONSUMPTION	8 1/2 GALLONS PER MINUTE AT 20 PSI

RTC F - 1500 SOLDER FUSION SYSTEM



RTC F – 1500 Solder Fusion System

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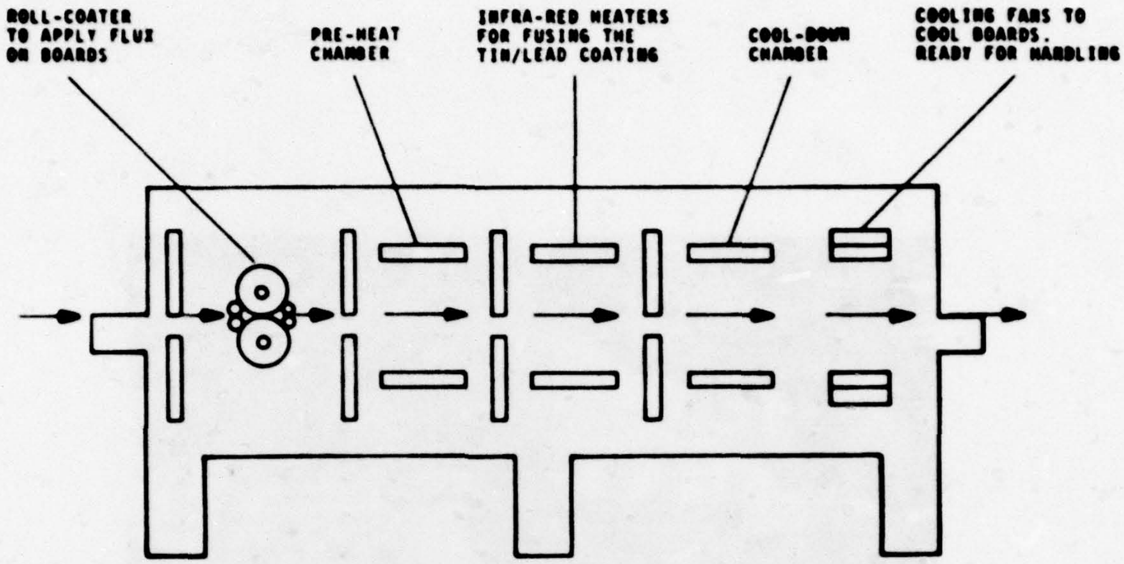
Fullerton, California

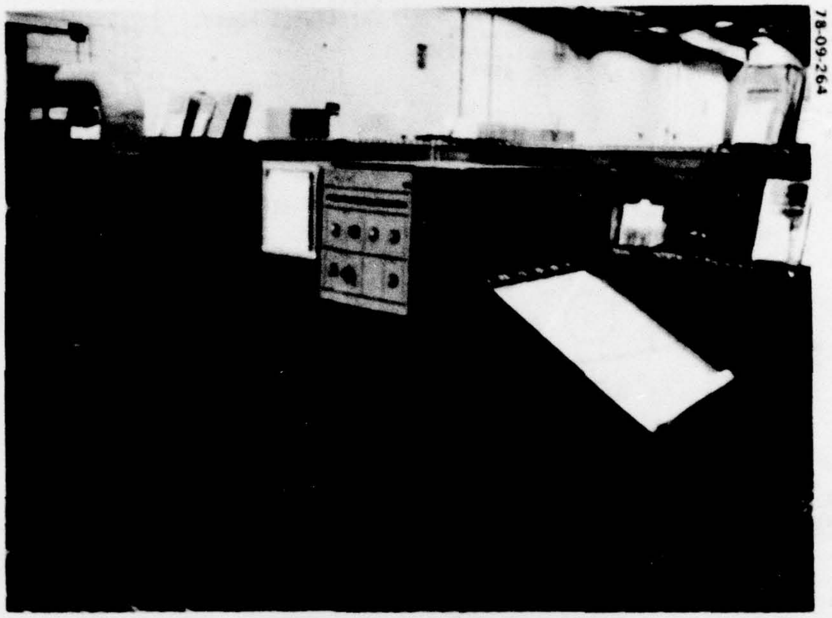
RTC F - 1500 SOLDER FUSION SYSTEM



SPECIFICATION:

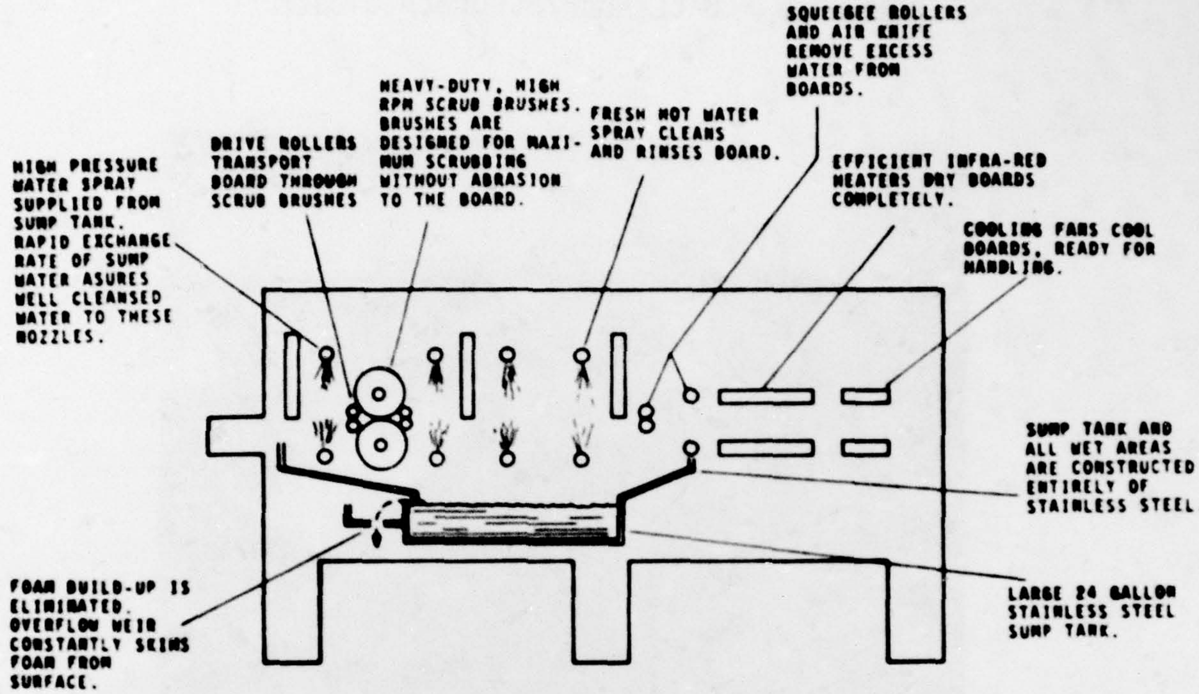
HEIGHT . . . . 57"
DEPTH. . . . . 32 1/2"
WIDTH. . . . . 108"
POWER REQUIREMENTS . . 25.2KW
MAXIMUM BOARD WIDTH. . 15"
POWER SUPPLY . . . . . 208/240/480 VAC
3 PHASE
CONVEYOR WIDTH . . . . 20"
CONVEYOR SPEED . . . . 0-20 FPM
HEATED WIDTH HIGH INTENSITY . . 16"
HEATED WIDTH PREHEAT . . . . . 18 1/2"

RTC G430 - B CLEANER/SCRUBBER SYSTEM



RTC G430 – B Cleaner/Scrubber System

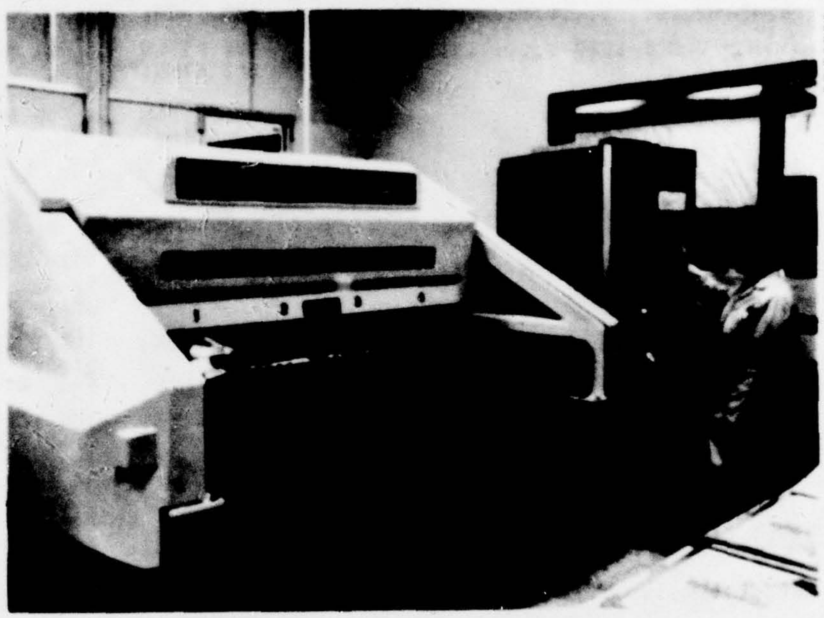
RTC G 430 - B CLEANER/SCRUBBER SYSTEM



SPECIFICATIONS

DIMENSIONS, OVERALL	
LENGTH	96 INCHES
HEIGHT	53 INCHES
WIDTH	46 INCHES
MAXIMUM BOARD WIDTH	24 INCHES
TRANSPORT SPEED	2 TO 20 FPM (VARIABLE)
SUMP DRAIN	2 INCH CPVC VALVE
DRYER SECTION	24 INCHES X 24 INCHES RADIANT HEATERS ABOVE AND BELOW CONVEYOR
WATER SUPPLY FITTINGS	8 1/2 GPM AT 20 PSI 3/4 INCH NPT
POWER SUPPLY	208 V, 60 Hz, 9 KW, 30 AMP 30
WEIGHT	900 POUNDS

EXCELLON XL - 3 D/R ROUTER



Excellon XL – 3 D/R Router

HUGHES-FULLERTON
Hughes Aircraft Company
Fullerton, California

EXCELLON XL - 3 D/R

WEIGHT AND SPACE DATA

SHIPPING WEIGHT (APPROX)	6000 LBS*
SEPARATE WEIGHT OF CNC CONSOLE	450 LBS
REQUIRED FLOOR SPACE:	
LENGTH	164 INCHES
WIDTH	180 INCHES
MAXIMUM FLOOR LOAD	400 PSI WITH FOOT BOLT PADS (27 ATMOSPHERES)
	*ADD 1000 LBS FOR OVERSEAS CRATING.

INPUT POWER

STANDARD	230 + 5%, - 10% VOLTS AC, SINGLE PHASE, 30A, 47-63 Hz
OPTIONS	208 + 5%, - 10% VOLTS AC, SINGLE PHASE, 30A, 47-63 Hz
	460 + 5%, - 10% VOLTS AC, SINGLE PHASE, 15A, 47-63 Hz

INPUT AIR

PRESSURE	95 - 150 PSIG
FLOW	20 SCFM
MAXIMUM TEMPERATURE	100°F (38°C)
HUMIDITY	-12°F (-24°C) MAXIMUM DEW POINT AT 1 ATM

HEAT EXCHANGER DATA

TYPE	FLUID-TO-AIR
MEDIA	CORROSION-INHIBITED DISTILLED WATER
PRESSURE AND FLOW	15 PSI AT 28 TO 35 GALLONS PER HOUR (3-SPINDLE CONFIGURATION)

VACUUM

CHIP REMOVAL METHOD	VACUUM AT PRESSURE FOOT
VACUUM	120 CFM, 16 INCH WATER LIFT, 1.5 INCH ORIFICE

APPENDIX B-5. TEST

Examination or Test	Applicable Specification	Ultra-Thin Copp			
		Peelable Carrier			
		17A591-1	17A591-2	17A591-3	17A591-4
1. Visual Examination	MIL-P-55110	Pass	Pass	Pass	Pass
2. Warp and Twist					
Warp, %	(None)*	2.7	6.5	3.5	1.1
Twist, %	(None)*	1.7	4.2	2.2	7.1
3. Plating Adhesion	MIL-P-55110	Pass	Pass	Pass	Pass
4. Plating Characteristics					
Conductor Thickness, In.	(None)*	0.0021	0.0022	0.0026	0.0021
PTH Wall Thickness, In.	MIL-STD-275	0.0019	0.0019	0.0023	0.0021
Ratio Thickness(Cond: PTH Wall)	(None)	1.08	1.16	1.13	1.00
PTH Cross-Section Quality	MIL-P-55640	Pass	Pass	Pass	Pass
5. Peel Strength, In./In. of Width					
As Received (Initial)	(None)*	6.7	7.4	7.5	8.1
After Thermal Stress	MIL-P-13949	8.6	9.4	10.2	10.5
After Thermal Cycling	MIL-P-13949	7.6	8.6	8.3	8.9
At 125°C	MIL-P-13949	8.3	9.5	9.3	11.0
6. Continuity (Thermal Shock)		Pass	Pass	Pass	Pass
Resistance Variance, % (Maximum)	MIL-P-55110	2.3	7.6	6.8	7.6
Post Thermal Shock Appearance	MIL-P-55110	Pass	Pass	Pass	Pass
7. Dielectric Strength (30KV Min.)					
Prior to Humidity Exposure	MIL-P-55110	Pass	Pass	Pass	Pass
After Humidity Exposure	MIL-P-55110	Pass	Pass	Pass	Pass
8. Insulation Resistance (Ω)					
Prior to Humidity Exposure	MIL-P-55110	40.5×10^{12}	22.0×10^{12}	5.3×10^{12}	34.5×10^{12}
At 5th Cycle	MIL-P-55640	13.0×10^{10}	25.5×10^{9}	37.0×10^{9}	16.5×10^{9}
At 10th Cycle	MIL-P-55640	87.0×10^{9}	21.5×10^{9}	13.7×10^{9}	20.0×10^{9}
9. Surface and Volume Resistivity					
Volume Resistivity (MegΩ-CM)	MIL-P-13949	2.2×10^{9}	6.3×10^{8}	9.4×10^{11}	3.0×10^{7}
Surface Resistivity (Meg Ω)	MIL-P-13949	2.5×10^{4}	22.5×10^{6}	5.3×10^{3}	4.6×10^{3}
10. Bond Strength					
2000 PSI Tensile Stress Test	MIL-P-55110	Pass	Pass	Pass	Pass
Appearance After Test	MIL-P-55110	Pass	Pass	Pass	Pass
11. Solderability	MIL-P-55110**				
Visual Quality	IPC-S-801	Pass	Pass	Pass	Pass
12. Water Absorption, %	MIL-P-13949	0.12	0.17	0.12	0.13

† Originally failed without FC/TMC cleaning; results are with FC/TMC cleaning

*No Military Requirement

**Requirement Only If Specified In Contract or P.O.

Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
3.5	4.6	3.4	5.6	4.7	4.6	2.3	0.9	2.6	0.5	1.6
3.8	2.9	2.2	3.6	3.0	2.9	1.5	0.6	1.7	0.3	1.0
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
0.0023	0.0019	0.0018	0.0014	0.0019	.0018	0.0024	0.0021	0.0018	0.0024	0.0022
0.0021	0.0019	0.0016	0.0016	0.0013	.0016	0.0025	0.0022	0.0018	0.0025	0.0023
1.09	1.00	1.13	0.88	1.42	1.11	0.96	0.95	1.0	0.96	0.97
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
7.4	9.1	8.9	8.4	8.2	8.7	13.5	12.5	11.1	12.8	12.5
9.7	9.9	10.3	8.9	9.0	9.5	16.2	13.0	17.1	10.8	14.3
8.4	8.1	8.4	8.4	7.8	8.3	13.3	13.0	13.5	10.0	12.5
9.5	11.4	11.0	9.3	9.8	10.4	8.5	5.3	5.0	7.2	6.5
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
6.1	6.5	6.8	3.9	8.4	6.4	2.6	2.4	5.5	2.8	3.3
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Reject	Pass
25.6×10^{12}	40×10^{12}	35×10^{12}	25×10^{12}	5×10^{12}	25×10^{12}	10^{10}	65×10^{9}	3×10^{11}	4×10^{11}	2×10^{11}
52.3×10^{9}	12×10^{9}	8×10^{9}	29×10^{9}	12×10^{9}	15×10^{9}	1.2×10^{10}	7×10^{9}	7×10^{10}	1×10^{7}	2.2×10^{10}
36.6×10^{9}	5×10^{9}	4×10^{9}	14×10^{9}	8×10^{9}	8×10^{9}	1×10^{10}	17×10^{9}	55×10^{9}	11×10^{6}	2×10^{10}
23.6×10^{10}	1.4×10^{9}	5.6×10^{8}	8.4×10^{8}	2.5×10^{8}	4.5×10^{8}	1.9×10^{9}	0.4×10^{9}	37.7×10^{9}	94×10^{10}	34×10^{9}
57.0×10^{4}	7.8×10^{5}	6.5×10^{5}	4×10^{5}	9.4×10^{5}	6.9×10^{5}	14×10^{5}	65×10^{5}	3.5×10^{5}	0.01×10^{5}	21×10^{5}
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
0.14	0.13	0.09	0.09	0.08	0.10	0.11	0.12	0.13	0.17	0.13

2.

2.3	0.9	2.6	0.5	1.6	1.3	0.9	1.0
1.5	0.6	1.7	0.3	1.0	0.8	0.6	1.0
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
0.0024	0.0021	0.0018	0.0024	0.0022	1.5	1.6	1.3
0.0025	0.0022	0.0018	0.0025	0.0023	1.3	1.3	1.3
0.96	0.95	1.0	0.96	0.97	1.2	1.3	1.0
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
13.5	12.5	11.1	12.8	12.5	14.0	18.0	16.9
16.2	13.0	17.1	10.8	14.3	15.4	16.2	16.8
13.3	13.0	13.5	10.0	12.5	15.9	20.7	16.6
8.5	5.3	5.0	7.2	6.5	9.2	8.8	8.3
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
2.6	2.4	5.5	2.8	3.3	2.9	1.8	3.5
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Pass	Pass	Pass	Reject	Pass	Pass	Pass	Pass
0^{10}	65×10^{9}	3×10^{11}	4×10^{11}	2×10^{11}	12×10^{12} ↑	15×10^{12} ↑	15.5×10^{12} ↑
$.2\times10^{10}$	7×10^{9}	7×10^{10}	1×10^{7}	2.2×10^{10}	30×10^{12} ↑	35×10^{12} ↑	75×10^{12} ↑
$\times10^{10}$	17×10^{9}	55×10^{9}	11×10^{6}	2×10^{10}	35×10^{12} ↑	45×10^{12} ↑	80×10^{12} ↑
$.9\times10$[illegible]	0.4×10^{9}	37.7×10^{9}	94×10^{10}	34×10^{9}	8.1×10^{10}	2.03×10^{9}	8.1×10^{10}
4×10^{5}	65×10^{5}	3.5×10^{5}	0.01×10^{5}	21×10^{5}	2.25×10^{4}	1.63×10^{4}	1.92×10^{4}
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass